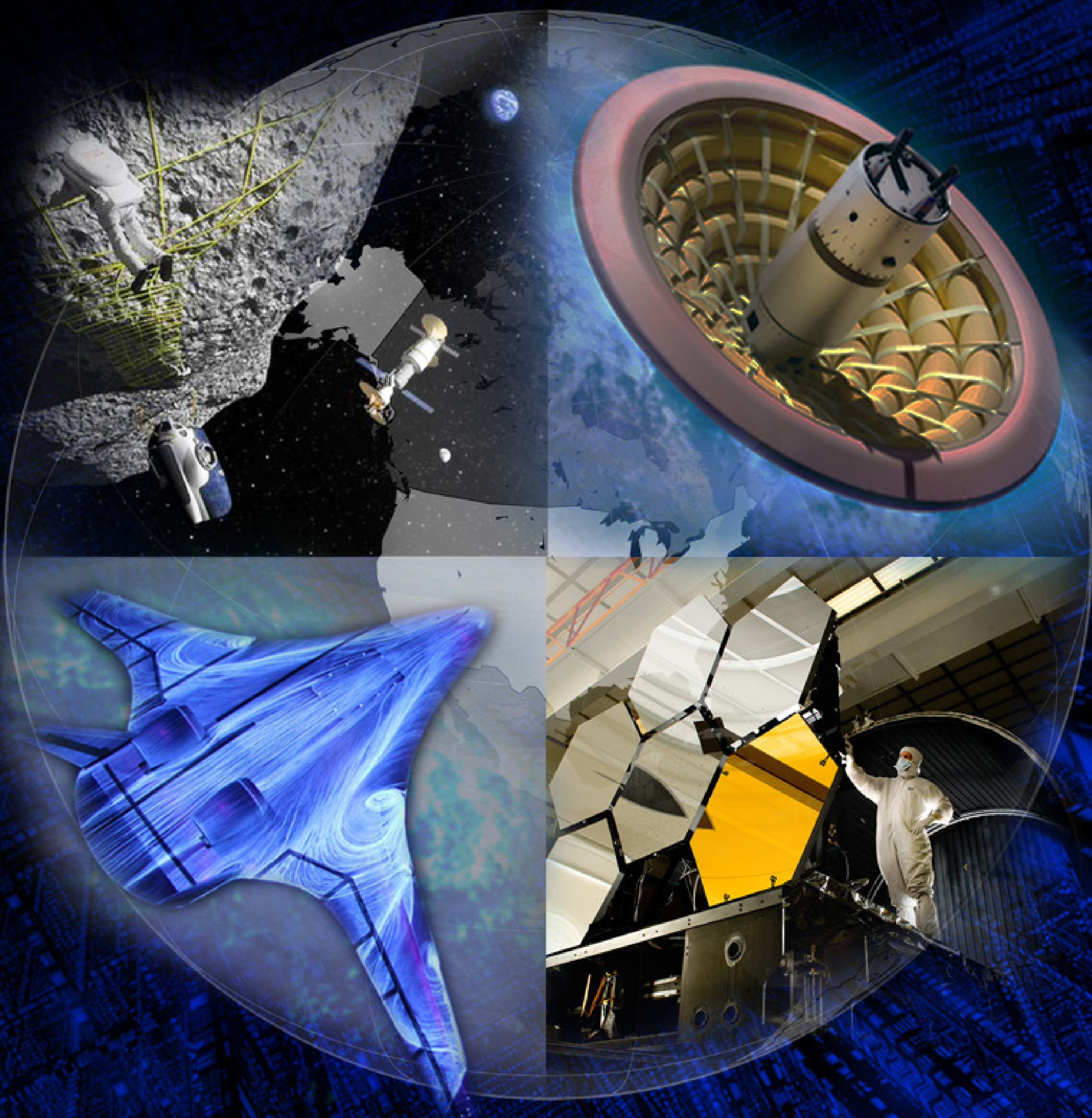
National Aeronautics and Space Administration

NASA Technology Roadmaps

TA 15: Aeronautics



May 2015 Draft

Foreword

NASA is leading the way with a balanced program of space exploration, aeronautics, and science research. Success in executing NASA's ambitious aeronautics activities and space missions requires solutions to difficult technical challenges that build on proven capabilities and require the development of new capabilities. These new capabilities arise from the development of novel cutting-edge technologies.

The promising new technology candidates that will help NASA achieve our extraordinary missions are identified in our Technology Roadmaps. The roadmaps are a set of documents that consider a wide range of needed technology candidates and development pathways for the next 20 years. The roadmaps are a foundational element of the Strategic Technology Investment Plan (STIP), an actionable plan that lays out the strategy for developing those technologies essential to the pursuit of NASA's mission and achievement of National goals. The STIP provides prioritization of the technology candidates within the roadmaps and guiding principles for technology investment. The recommendations provided by the National Research Council heavily influence NASA's technology prioritization.

NASA's technology investments are tracked and analyzed in TechPort, a web-based software system that serves as NASA's integrated technology data source and decision support tool. Together, the roadmaps, the STIP, and TechPort provide NASA the ability to manage the technology portfolio in a new way, aligning mission directorate technology investments to minimize duplication, and lower cost while providing critical capabilities that support missions, commercial industry, and longer-term National needs.

The 2015 NASA Technology Roadmaps are comprised of 16 sections: The Introduction, Crosscutting Technologies, and Index; and 15 distinct Technology Area (TA) roadmaps. Crosscutting technology areas, such as, but not limited to, avionics, autonomy, information technology, radiation, and space weather span across multiple sections. The introduction provides a description of the crosscutting technologies, and a list of the technology candidates in each section.

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Executive Summary

This is Technology Area (TA) 15: Aeronautics, one of the 16 sections of the 2015 NASA Technology Roadmaps. The Roadmaps are a set of documents that consider a wide range of needed technologies and development pathways for the next 20 years (2015-2035). The roadmaps focus on "applied research" and "development" activities.

This is the first Aeronautics technology roadmap. It reflects previous Aeronautics Research Mission Directorate (ARMD) technology planning work that complies with Executive Order 13419, signed December 20, 2006. The Executive Order required a comprehensive research and development policy to guide U.S. aeronautics research and development programs through the year 2020. This TA is intended to align with the NASA Aeronautics Strategic Implementation Plan (SIP) to be published in 2015. NASA Aeronautics organized the technology roadmap around six current Strategic Thrusts with inputs from other organizations, industry, and academia. Because of the dynamic nature of the Aeronautics program, the material in this roadmap will be updated regularly.

The Aeronautics planning framework consists of Strategic Thrusts, Research Themes, and Challenges. The six Strategic Thrusts are: 1) safe, efficient growth in global aviation, 2) innovation in commercial supersonic aircraft, 3) ultra-efficient commercial vehicles, 4) transition to low-carbon propulsion, 5) real-time system-wide safety assurance, and 6) enable assured machine autonomy for aviation. Each thrust represents several Research Themes, or long-term research efforts. The Technical Challenges are addressed in the work conducted under the Research Themes. Organizing long-term research efforts under these themes helps ensure that research remains strategic.

Research Strategy

The NASA Aeronautics research strategy is to develop and demonstrate revolutionary technologies that enable global air transportation that is safer, more efficient, and more environmentally friendly for the next 30 years and beyond.

NASA's Next Generation Air Transportation System (NextGen) work will enable significant growth (perhaps two fold) over the current volume in global aviation by supporting safe, efficient, autonomous vehicles, and protection of the environment. This research will deliver capabilities to safely optimize air traffic volume, integrate unmanned vehicles, enhance pilot and controller situational awareness, and detect and prognosticate airspace system-wide safety threats ranging from months to days to minutes.

NASA will enable commercial supersonic technologies that allow private industry to develop a viable commercial supersonic aircraft. These technologies will reduce the sonic boom signature by 25 perceived level decibels (PLdB). This effort is also working to reduce the community noise level to 10 dB below International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) stage 4, with a 50 percent improvement in fuel efficiency. NASA is also establishing acceptable sonic boom noise criteria for supersonic flight overland in the United States.

NASA is also developing technologies for ultra-efficient subsonic commercial vehicles. These technologies will enable the simultaneous attainment of NASA's subsonic fixed-wing transport 2035 goals of a 52 dB (cumulative) reduction in community noise relative to ICAO and FAA stage 4 levels, an 80 percent reduction in emissions of nitrogen oxides (NOx) relative to Committee on Aviation Environmental Protection (CAEP6) standards, and a 60 percent reduction in fuel burn compared with 2005 best-in-class aircraft levels. Ultra-efficient commercial technology goals will be achieved through advanced efficient engines using low-NOx combustors and hybrid-electric propulsion systems, drop-in alternative fuels, and a variety of other technologies to reduce vehicle drag, structural weight, and noise. NASA has rotary-wing 2025 goals that include a 50 percent variation in rotor speed using variable-speed power turbine concepts and two-speed drive systems that will enable greater efficiencies in both hover and high-speed cruise, significantly improving fuel efficiency and reducing community noise.

Table 1. Summary of Level 2 Thrusts for TA 15

15.0 Aeronautics	**Strategic Objective:**	**Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan)**
15.1 Safe, Efficient Growth in Global Aviation	Thrust Description:	Enable a NextGen air transportation system in the U.S. by 2035 and safely expand capability of the global airspace system to accommodate growth in air traffic.
15.2 Innovation in Commercial Supersonic Aircraft	Thrust Description:	Provide low-boom standard, efficiency, and noise reduction technologies that could lead to commercial supersonic flight overland.
15.3 Ultra-Efficient Commercial Vehicles	Thrust Description:	Pioneer technologies for future generations of commercial transports that simultaneously reduce noise, fuel use, and emissions.
15.4 Transition to Low-Carbon Propulsion	Thrust Description:	Enable transition of industry to low-carbon fuels and alternative propulsion systems.
15.5 Real-Time System-Wide Safety Assurance	Thrust Description:	Develop tools for use in a prototype of an integrated safety monitoring and assurance system that detects, predicts, and prevents safety problems in real time.
15.6 Enable Assured Machine Autonomy for Aviation	Thrust Description:	Enable the utilization of higher levels of automation and autonomy across the aviation system including routine Unmanned Aircraft System (UAS) presence in the National Air Space (NAS).

Benefits

Current forecasts for worldwide aviation activities predict a vast increase in air transportation of all forms, including piloted and unpiloted. NASA's NextGen work will safely increase the throughput of the air traffic system (ATS) in a cost-efficient, environmentally friendly way, using state of the art technology to accommodate the predicted large increase in worldwide air traffic. NextGen will provide advanced safety prognostics, increased pilot awareness of off-nominal conditions, and optimized air and surface operations, including trajectory-based operations (TBO) and dynamic weather routing. NextGen automation of routine unmanned aircraft system (UAS) access to the National Airspace System (NAS) will unlock the vast potential of UASs to provide safety, efficiency, and cost savings to tomorrow's ATS.

Commercial supersonic vehicles have great promise for enhancing air travel into the next century. Establishing criteria for community tolerance of overland sonic booms is vital to future commercial supersonic aircraft. Enhanced, validated design tools to predict sonic boom levels will reduce the sonic boom signatures of future vehicles. Low noise configuration concepts will open the door to future commercial supersonic vehicles.

The global increase in air travel will require commercial vehicles to be more efficient than ever before. The commercial aircraft of tomorrow will have to be low-cost, low-noise, with low environmental impact, and be easier to manufacture and operate. Advanced commercial aircraft configurations, structures technology, and engine technology will ultimately keep the operating costs, fuel consumption, and environmental and community noise impacts to a minimum as global air traffic steadily increases for the rest of the century.

Low-carbon propulsion systems will help to achieve environmental sustainability by enabling absolute reductions in carbon emissions, and will provide large gains in reducing the impact of aviation on climate change.

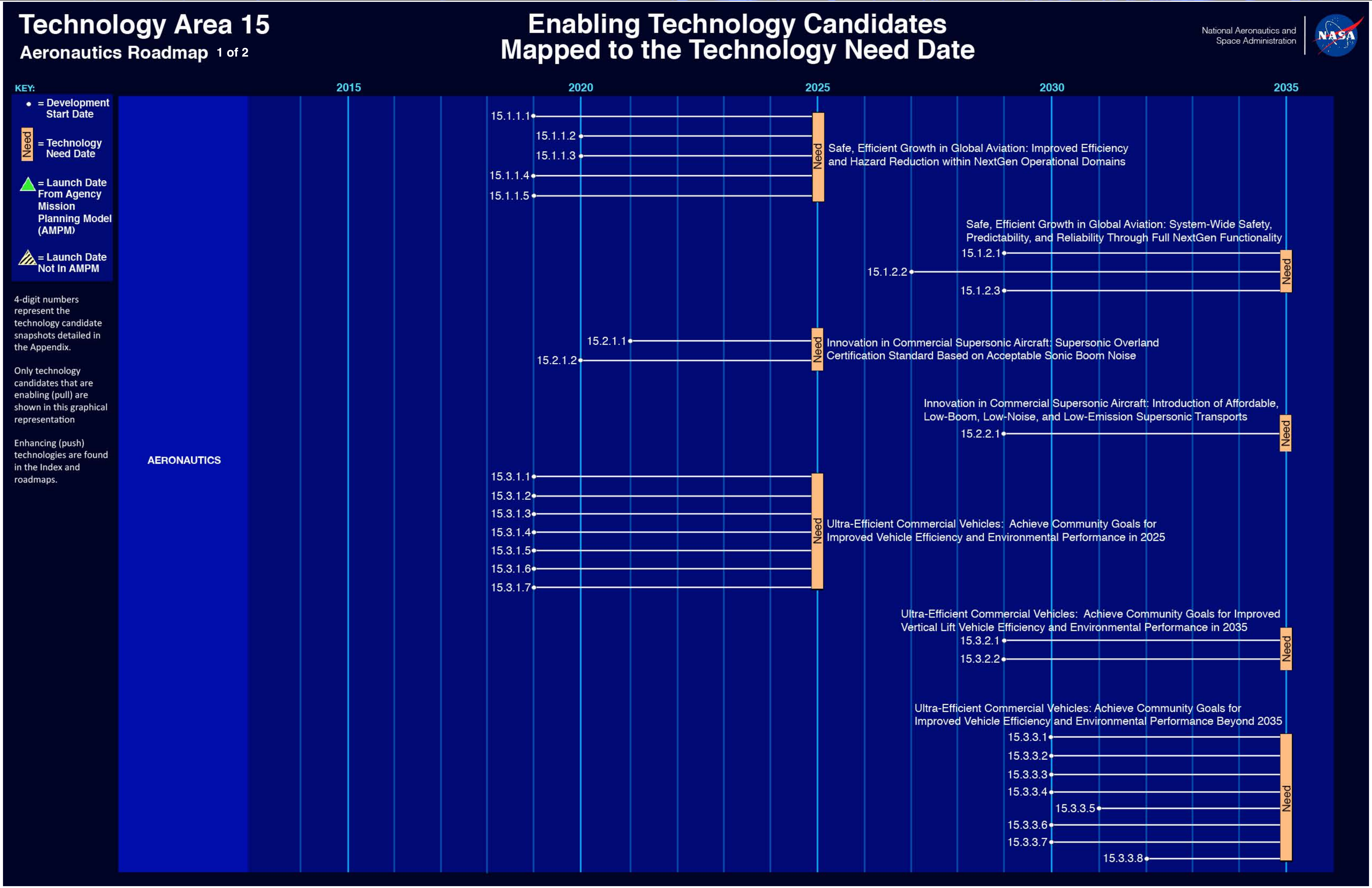


Figure 1. Technology Area Strategic Roadmap

Technology Area 15
Aeronautics Roadmap 2 of 2

Enabling Technology Candidates Mapped to the Technology Need Date

National Aeronautics and Space Administration

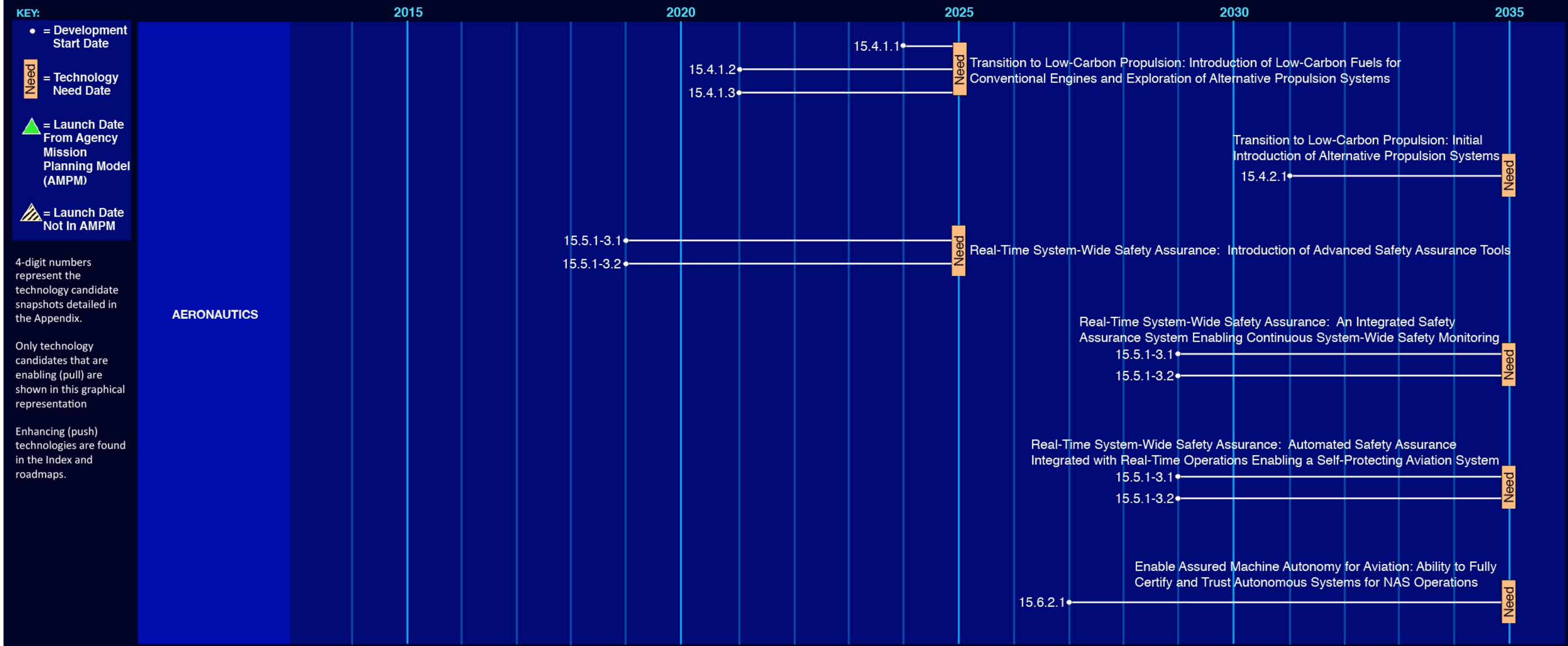


Figure 1. Technology Area Strategic Roadmap (Continued)

Introduction

The Technology Area (TA) 15 Aeronautics roadmap is based on NASA Aeronautics Research Mission Directorate (ARMD) technology planning work that complies with requirements from a 2006 Executive Order (EO13419) calling for a comprehensive research and development policy to guide U.S. aeronautics research and development programs through the year 2020. This roadmap is intended to align with the NASA Aeronautics Strategic Implementation Plan (SIP), which will be published in 2015.

NASA applied the same planning process to produce all roadmaps. However, the TA 15 roadmap is unique because it reflects terminology that is specific to Aeronautics planning efforts. In this roadmap, Aeronautics Strategic Thrusts serve the same function as Mission Classes in the space community. Also, Roadmap Outcomes are similar to Level 3 tasks in other roadmaps. These serve the same function as Design Reference Missions (DRM) for the space community. The TA 15 Level 4 work is organized into Research Themes. These Research Themes are long-term technology efforts intended to provide continuity as the current technology challenges are completed and new challenges are planned for the same area. Some Research Themes apply to more than one Level 4 work task. Technical challenges are addressed within the Research Theme framework.

This Aeronautics Roadmap is organized into six aeronautics Strategic Thrusts that are equivalent to TA Level 2 activities. These Strategic Thrusts have evolved from national-level plans, systems analysis, and stakeholder input. The six Strategic Thrusts are: 1) safe, efficient growth in global aviation, 2) innovation in commercial supersonic aircraft, 3) ultra-efficient commercial vehicles, 4) transition to low-carbon propulsion, 5) real-time system-wide safety assurance, and 6) enable assured machine autonomy for aviation. Each Level 2 effort has been further divided into Level 3 efforts, as seen in Figure 2.

15.1 Safe, Efficient Growth in Global Aviation

The technical focus of Strategic Thrust 1 is on future air traffic system concepts, operations, technologies, and high-fidelity simulation. NASA plays two primary roles within this thrust. The first is to develop key safety and automation technologies that enable and extend the benefits for the NextGen Air Transportation System (ATS). The second role is to look beyond current plans, researching and developing transformative concepts and technologies to ensure that a long-term research base is in place to support future planning, enable transformative approaches to future operations, and safely extend the capabilities and range of uses of the National Airspace System (NAS). In order to accomplish these goals, a high-fidelity, integrated, virtual, and distributed next-generation air traffic control simulation will be developed and used.

Level 3 efforts are defined as follows:

- **15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains:** Over the next decade, implementation of NextGen research results will proceed incrementally in specific operational domains based on prioritized community needs. For example, the Precision Departure Release Capability, recently developed by NASA and transferred to the FAA, enables precise aircraft departures to ensure that they seamlessly merge into overhead aircraft streams. This tool increases en-route capacity, improves reliability of service, and reduces fuel use. Specific prioritized NextGen improvements such as this one will overcome major operational hurdles and choke points, delivering increased efficiency and safety, reducing environmental impact, and improving efficiency of operations for airlines and general aviation.

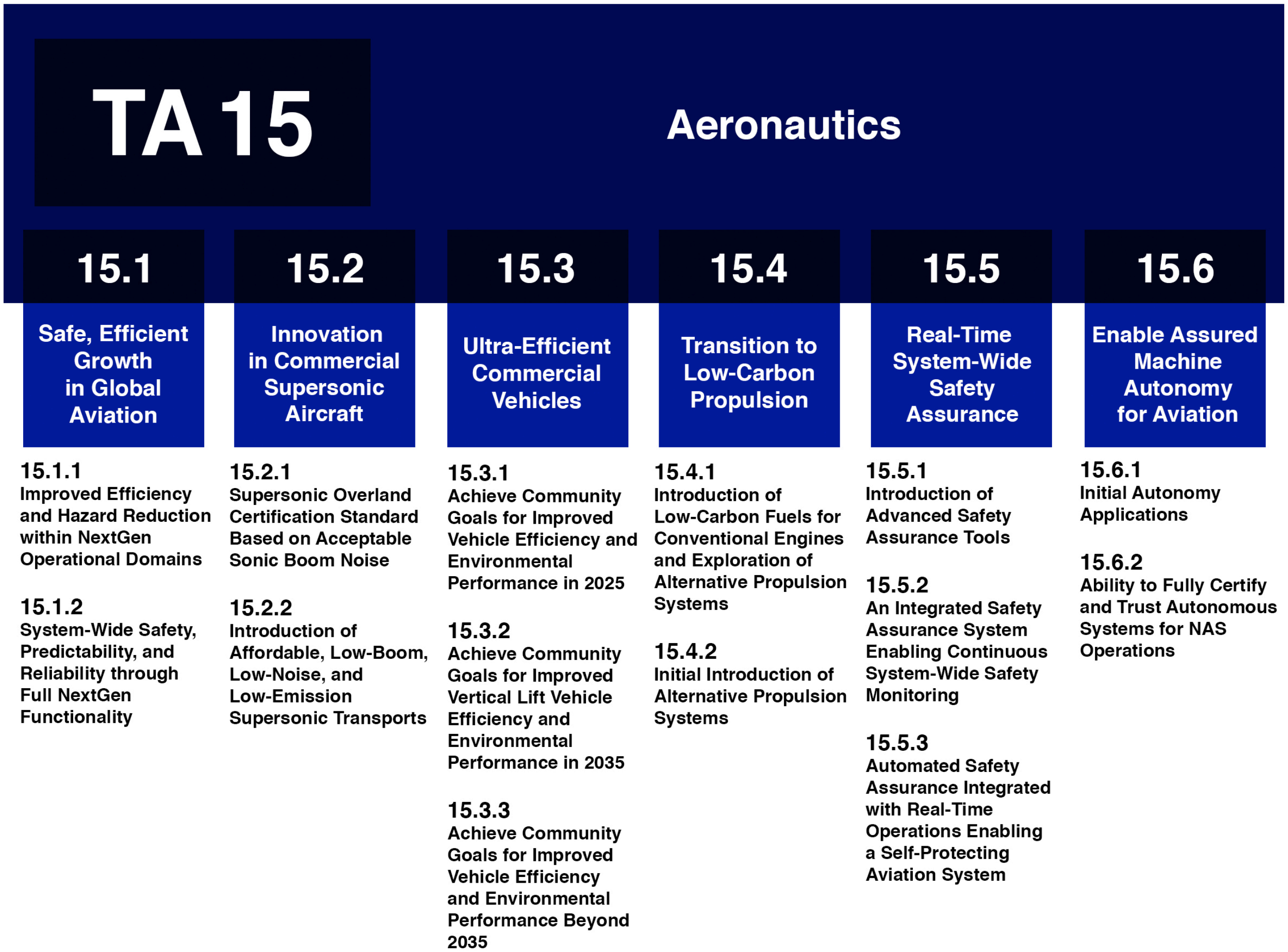


Figure 2. Technology Area Breakdown Structure (TABS) for Aeronautics

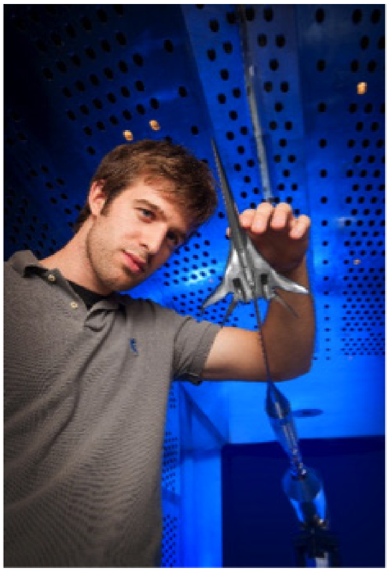
- **15.1.2 System-Wide Safety, Predictability, and Reliability through Full NextGen Functionality:** The decade from 2025 to 2035 will see transformation of the NAS through introduction of the full array of NextGen technologies, including proactive and prognostic safety practices for air traffic management concepts, reliable and capable automation, management of emerging risks, and integration of functions and systems that are currently separated. These advances will increase the capacity, safety, and efficiency of the NAS, while accommodating an increasing variety of missions and vehicle types, including full integration of unmanned aircraft system (UAS) operations. Into the future, technology advances will allow the Nation to look beyond NextGen to enhance system safety, flexibility, scalability, and resilience. The beyond-NextGen system will enable global traffic growth, support significant changes in the business-network models of airspace users, and accommodate autonomous aircraft operations. Autonomous system-wide adaptation to real-time conditions and events will enable dynamic optimization of system operations and serve an expanded variety of aircraft and missions.

15.2 Innovation in Commercial Supersonic Aircraft

Viability of commercial supersonic service depends on permissible supersonic flight overland and meeting the environmental constraints imposed on subsonic aircraft. NASA's technical focus, therefore, is on determining the sonic boom level acceptable to the public, enabling vehicle designs that achieve it, and delivering methods and technologies that industry could use to produce a viable supersonic transport.

Level 3 efforts are defined as follows:

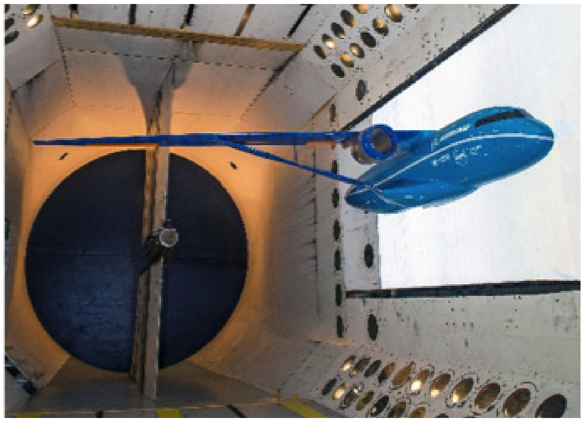
- **15.2.1 Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise:** Over the next decade (2015-2025), research will focus on overcoming the adverse impact of sonic boom in order to alleviate public concern and environmental impacts. Success in this research will enable the return of civil supersonic service that was abandoned in 2003, while expanding those services in terms of range and efficiency.
- **15.2.2 Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports:** In the subsequent decade (2025-2035), building on success in 2015-2025, research in the additional challenges of landing and take-off noise, high-altitude emissions, and fuel efficiency will enable affordable, low-boom, low-noise, and low-emission supersonic transportation accessible to a broader range of the traveling public. Introduction of supersonic civil air transportation in 2025-2035 will provide the impetus for further research and development that can ultimately yield additional benefits for air travelers, the U.S. economy, and global connectivity.



Subscale model of a potential future low-boom supersonic aircraft

15.3 Ultra-Efficient Commercial Vehicles

This Strategic Thrust aims primarily at the generations of aircraft that will follow those now being developed. The community vision for this Strategic Thrust is based primarily on improved environmental performance to address growing public concerns over environmental sustainability, as well as increased efficiency and flexibility of future air vehicles to achieve better economics and reduced fuel use. These goals will be pursued through wing aspect ratio optimization, advanced composite research, advanced engine component development, improvement in computation fluid dynamics (CFD) modeling, and advanced configuration studies. These future vehicles will enable worldwide growth in aviation while providing lower noise and diminished impact on air quality and climate change.



15 percent scaled model of advanced high aspect ratio wing design in a wind tunnel

Level 3 efforts are defined as follows:

- **15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025:** Over the next decade (2015-2025), community efforts will focus on maturing and incorporating emerging technology improvements for the next generation of aircraft.

- **15.3.2 Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035:** In the mid-term decade (2025-2035), new transport-class vehicles will achieve desired levels of efficiency and environmental compatibility. Concurrently, new vertical lift designs will achieve improved levels of noise, efficiency, and environmental compatibility.
- **15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035:** Advanced transport vehicles will approach efficiency and environmental compatibility desired for this timeframe. Further in the future, new transports will achieve higher levels of efficiency and environmental performance. NASA is currently exploring community views for vertical lift aircraft in this timeframe.

15.4 Transition to Low-Carbon Propulsion

NASA will help achieve low-carbon propulsion through research in two areas. The first research area involves the development of a suite of certified, commercially-available alternative fuels that will lower the carbon footprint of traditional piston-and-gas turbine engines and their future derivatives. This research will be conducted in partnership with the aviation community, The second research area involves exploring the possibility of achieving very low- or no-carbon emissions through new propulsion systems that use alternative, low-carbon, and possibly renewable fuels.

Level 3 efforts are defined as follows:

- **15.4.1 Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems:** Over the next decade (2015-2025), a suite of lower life-cycle carbon jet fuels will become available for conventionally-powered aircraft. At the same time, research will culminate in possible early applications in the general aviation sector of hybrid and fully-electric propulsion systems.
- **15.4.2 Initial Introduction of Alternative Propulsion Systems:** In the subsequent decade (2025-2035), extensive research on a selected range of propulsion systems and aircraft configurations will enable possible initial deployment of these technologies on regional jet or single-aisle transport aircraft.

15.5 Real-Time System-Wide Safety Assurance

Commercial aviation is the safest mode of transportation. This enviable record results from decades of continuous improvement in reaction to known hazards, incidents, and accidents. As volume in the air transportation system increases, the ATS will have to exploit technology advances to enhance the capacity, efficiency, and uses of the NAS. It will be vital to recognize and quickly mitigate emerging safety issues in real time before they become hazards.

Rapid advances in sensor and networking technology and integration, combined with advanced data analytics, will enable unprecedented insight into system operations, health, and safety. These advances, applied broadly within the aviation system and combined with system-of-systems modeling and prognostics, offer a new vision of real-time, system-wide safety assurance. This Strategic Thrust will deliver a progression of capabilities that accelerate the detection, prognosis, and resolution of system-wide threats.

Level 3 efforts are defined as follows:

- **15.5.1 Introduction of Advanced Safety Assurance Tools:** Over the next decade (2015-2025), continued development of safety tools like data mining and analysis, prognostics, real-time system assurance techniques, and safety risk modeling will improve the ability to gain insights and develop solutions. Taking advantage of the increasing availability of aviation system data, identification of safety issues will focus on scaling currently-available data mining technologies to process system-wide data. Increased speed and accuracy of analysis tools will support progress toward real-time identification of precursors to emerging safety issues.

- **15.5.2 An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring:** In the subsequent decade (2025-2035), integration of analysis into a live virtual simulation of the NAS will provide a comprehensive picture of system health and facilitate coordination of mitigation strategies. This capability will improve safety assurance through earlier detection of trends and risks system-wide. More highly automated safety assessments will enable continuous safety assurance, and an automated system will evolve over the decade to enable near-real-time assessments as confidence increases in regularly-validated system judgments.
- **15.5.3 Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System:** The automated safety assurance system will become integrated with real-time operations to help create an aviation system that exhibits the properties of self-protection and self-healing. In the more distant future, human operators and autonomous systems will collaborate to ensure an optimal mix of corrective actions—from immediate operational adjustments to longer-term system and infrastructure changes—in order to minimize safety risks. Work will culminate in an integrated demonstration of a prototype real-time, system-wide safety assurance system.

15.6 Enable Assured Machine Autonomy for Aviation

Autonomy applied to a broad spectrum of activities promises to be one of the most transformative technologies of the future. The technical focus of Strategic Thrust 6 is to develop high-impact autonomy applications, operating in harmony with humans, to maximize the benefits of aviation to society.

To achieve these benefits, NASA will conduct research in several areas, leveraging accelerating developments in machine learning, robotics, and autonomy. Extensive capabilities to verify and validate highly complex software-intensive systems will be developed, as well as testbeds to understand key challenges and develop solutions for specific applications. This effort will develop autonomy standards, technologies, functions, and applications. Architectures and design tools will be developed to define effective joint human-machine cognitive systems. Aeronautics will exploit and expand NASA-wide resources to provide a robust test environment with relevant capabilities for developing technologies, concepts, and architectures associated with autonomous systems.

Level 3 efforts are defined as follows:

- **15.6.1 Initial Autonomy Applications:** Research for the near-term (2015-2025) will help the initial integration of UAS capabilities into the NAS. Through community-wide collaboration, ARMD will also identify and investigate opportunities for exploiting autonomous systems within the near-term aviation infrastructure. For example, research will address growing community interest in enabling the operation of small, highly-automated vehicles within specially designated areas, as well as integration with more conventional aviation operations where appropriate. Other early applications of autonomy, such as autonomous emergency landing systems, will improve system performance and safety. Research for this timeframe will help define the benefits and risks of potential autonomous systems, facilitating selection of the most appropriate candidates for focused research and application. Evolution of the test infrastructure will support critical exploration and validation activities.
- **15.6.2 Ability to Fully Certify and Trust Autonomous Systems for NAS Operations:** In the far-term, NASA research will help to enable the widespread use of autonomy across a broad range of NAS functions. Development of techniques for verification, validation, and systems certification of complex, joint human-machine cognitive systems will support efforts to establish trust in autonomous systems and allow for eventual certification of the full range of autonomous operations.

TA 15.1: Safe, Efficient Growth in Global Aviation

Currently, ATS personnel sequence and space arrivals into busy airports using limited arrival scheduling automation, data from radar, and visual identification. Poor predictability of surface movements and scheduling exist due to extreme differences in carrier and operator procedures, as well as non-coordinated technologies used throughout the country. Groups of aircraft are manually routed around forecast weather systems. ATS personnel advise pilots of significant weather issues and recommend changes as required for the continued safe operation of the flight. Trans-oceanic routes are manually separated using downlinked data.

The goal of this Strategic Thrust is to improve and enhance the current ATS. This will be needed in order to accommodate the global increase in air traffic predicted for the next century. By applying advanced aircraft- and ground-based technologies with a virtual simulation environment, new advances in ATS technologies can be developed and validated that will improve safety, reduce operating costs, and reduce environmental impacts for the future of air travel.

Aircraft health monitoring will also play a role in improving and enhancing the ATS. Work on advanced engine health monitoring will improve situational awareness and allow for expedited ATS procedures for aircraft with mechanical difficulties.

Accommodation of the predicted increase in ATS volume requires implementation of advanced coordinated technology. A high-fidelity modeling and testing environment is being developed for the demonstration of advanced capacity, efficiency, and safety solutions.

Thrust Description

NASA must safely and smoothly provide a path for technology infusion to the next generation air traffic system. To do this, NASA will take a spiral, gradual approach to implementing technology. This staged and layered approach requires high-fidelity virtual environments for complete demonstration of new tools and concepts.

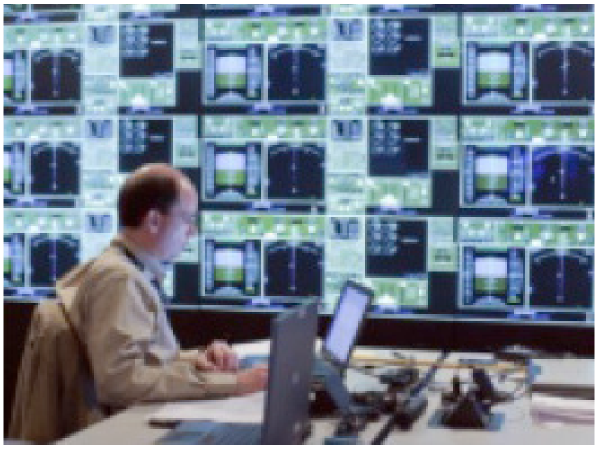
Table 2. Summary of Level 3 Outcomes for Thrust 15.1

Level 1		
15.0 Aeronautics	Strategic Objective:	Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan).
Level 2 - Thrust Name		
15.1 Safe, Efficient Growth in Global Aviation	Thrust Description:	Enable a NextGen air transportation system in the U.S. by 2035 and safely expand capability of the global airspace system to accommodate growth in air traffic.
Level 3 - Outcome Name		
15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains	Outcome Description:	Over the next decade, implementation of NextGen research results will proceed incrementally in specific operational domains based on prioritized community needs. For example, the Precision Departure Release Capability, recently developed by NASA and transferred to an other government agency, enables precise aircraft departures to ensure that they seamlessly merge into overhead aircraft streams. This tool increases en route capacity, improves reliability of service, and reduces fuel use. Specific prioritized NextGen improvements such as this one will overcome major operational hurdles and choke points, delivering increased efficiency and safety, reducing environmental impact, and improving efficiency of operations for airlines and general aviation.
	Research Theme(s):	Advanced Operational Concepts, Technologies, and Automation - Research and development of operational efficiency incorporating proactive safety risk management in operational domains.
	Benefits:	Improves air traffic efficiency in all phases of operations using an integrated approach to surface operations, weather rerouting, and trans-oceanic operations. Improves safety levels in an environment of rapid air traffic volume growth. Provides a platform to develop advanced air traffic system technologies beyond the current manual uncoordinated implementation.
15.1.2 System-Wide Safety, Predictability, Reliability through Full NextGen Functionality	Outcome Description:	The 2025-2035 decade will see transformation of the NAS through introduction of the full array of NextGen technologies, including proactive and prognostic safety practices for air traffic management concepts, reliable and capable automation, management of emerging risks, and integration of currently separated functions and systems. These advances will increase the capacity, safety, and efficiency of the NAS, while accommodating an increasing variety of missions and vehicle types, including full integration of UAS operations. Into the future, technology advances will allow the Nation to look beyond NextGen to enhance system safety, flexibility, scalability, and resilience. The beyond-NextGen system will enable global traffic growth, support significant changes in the business-network models of airspace users, and accommodate autonomous aircraft operations. Autonomous system-wide adaptation to real-time conditions and events will enable dynamic optimization of system operations and serve an expanded variety of aircraft and missions.
	Research Theme(s):	1) Safety Management for Emergent Risks - Research and development of prognostic safety risk management solutions and concepts for emergent risks. 2) Integrated Modeling, Simulation, and Testing - Development, validation, and application of advanced modeling, simulation, and testing capabilities to assess integrated, end-to-end NextGen Trajectory-Based Operations functionality and seamless UAS operations, as well as other future aviation system concepts and architectures. 3) Airspace Operations Performance Requirements - Advanced research to develop performance requirements, functional allocation definitions, and other critical data for integrated, end-to-end NextGen Trajectory-Based Operations functionality, and seamless UAS operations, as well as other future aviation system concepts and architectures.
	Benefits:	Provides system-wide, real-time integrated safety and risk management capability to the national ATS. Evaluates new Air Traffic Management (ATM) concepts using advanced simulation capabilities. Reduces risk within the NextGen ATS.

TA 15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains

NASA's near-term (2015 - 2025) effort will aim to maximize the NextGen's state of the art (SOA) technologies for early improvements in operational efficiency, safety, and environmental performance. Improving on the current manual, non-coordinated ATS traffic management, NASA will integrate ground- and aircraft-based technologies for airport surface operations management, aircraft airborne spacing, real-time weather rerouting, and trans-oceanic routing.

Technical Challenges



Air Traffic Operations Lab (ATOL)

This area will use the NextGen simulation environment to demonstrate increased airborne arrival throughput while maintaining safety using integrated aircraft- and ground-based automation technologies. Further research will determine appropriate targets for increasing throughput. This effort will also increase efficiency of airport operations, including arrivals, departures, and surface operations, while reducing safety risks and impacts to the environment, including emissions and noise. Integrating weather forecasts and nowcasts with aircraft operations, traffic flow, and airspace management strategies will reduce weather-induced delays and safety risks. Oceanic airspace operational efficiency will be improved by integrating air and ground procedures and technologies that enable reduced-separation minima and optimized routes and reroutes, reducing trans-oceanic delays. Specific performance targets will be determined by future research.

Benefits of Technology

This work will provide improved air traffic efficiency in all phases of operations using an integrated approach to surface operations, weather rerouting, and trans-oceanic operations. Safety levels will be maintained or improved in an environment of rapid air traffic volume growth.

Table 3. TA 15.1.1 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.1.1.1	Increase Throughput	Increase arrival throughput while maintaining safety, using integrated aircraft-based and ground-based automation technologies.
15.1.1.2	Increase Terminal Efficiencies	Increase arrivals, departures, and surface operations efficiency while increasing overall throughput and reducing safety risks.
15.1.1.3	Reduce Weather Delays and Risks	Reduce weather-induced delays and safety risks by integrating weather forecasts and nowcasts with aircraft operations, traffic flow, and airspace management strategies.
15.1.1.4	Improve Efficiency of Oceanic Operations	Safely increase oceanic airspace operational efficiency by integrating air and ground procedures and technologies that enable reduced-separation minima and optimized routes and reroutes.
15.1.1.5	Develop Methods for Real-Time Assessment of Overall Engine Health	Develop and implement advanced systems for real-time assessment of overall aircraft engine health.

TA 15.1.2 System-Wide Safety, Predictability, and Reliability through Full NextGen Functionality

In the mid- and far-terms (2025-2035, and beyond), NASA will enable advanced methods for safety risk management by pursuing a reduction in aircraft incidents through automatic in-flight spacing, advancing human and automated interfaces that exploit human strengths and account for human limitations, and advancing vehicle systems monitoring. A virtual human-in-the-loop testing environment will be developed to demonstrate trajectory-based operations, optimized air and ground functional allocations, and complex decision-making.

Air Traffic Control (ATC) Lab

Technical Challenges

The objective in this area is to research and develop prognostic safety risk management solutions and concepts for emergent risks. NASA will be pursuing technologies for safe aircraft separation and advanced human-centered technologies that exploit human strengths, account for human limitations, and support complex situational awareness. This area will further develop the NextGen simulation environment to validate future aviation system concepts and architectures, such as trajectory-based operations, in a continuing effort until 2035. NextGen system-level studies will examine all aspects of NextGen safety, efficiency, and capacity. The efforts will be measured by the number of NextGen users around the country, percent cost reduction of Air Traffic Management (ATM) operations, percent increase of distributed operations, and percent risk reduction within accident categories and in emergent hazards.

Benefits of Technology

This technology will provide the first system-wide, real-time, integrated safety and risk management capability to the national ATS and will add the benefit of being able to evaluate new ATM concepts using advanced simulation capabilities. This integrated system shows promise to significantly reduce risk within the NextGen ATS, even as global air traffic increases as much as two fold in the future.

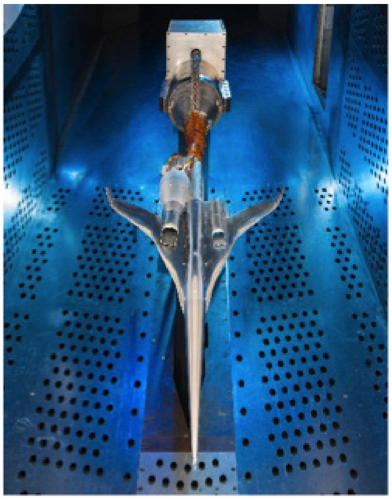
Table 4. TA 15.1.2 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.1.2.1	Reduce Occurrences of Crew Loss of Aircraft State Awareness	Develop technologies and training processes that mitigate problems and contributing factors that lead to flight crew loss of aircraft state awareness.
15.1.2.2	Develop Virtual Environment Testing	Develop a cloud-based, live, virtual, and constructive simulation of the National Airspace System to perform integrated, multi-fidelity evaluations of future concepts, technologies, and architectures on the basis of system-level performance, safety, environmental impacts, and benefit.
15.1.2.3	Optimize Air/Ground Functional Allocations	Perform a design space exploration and make recommendations for the allocation of en route separation assurance functions to human operators and automation systems on the ground and in the air on the basis of system-level performance, safety, and economic values.

TA 15.2: Innovation in Commercial Supersonic Aircraft

The last viable commercial supersonic aircraft used 1960s technology and had a perceived level sonic boom of 105 decibels. This aircraft was never approved for overland flight in the United States.

Viability of a commercial supersonic aircraft depends on permissible supersonic flight overland and meeting the environmental constraints imposed on subsonic aircraft. NASA's technical focus is on determining an acceptable sonic boom noise level, developing designs that achieve it, and delivering methods and technologies that industry could use to produce commercial supersonic transport.



Wind tunnel design validation of sonic boom signatures, inlet and nozzle effects

Long-term technical needs for supersonic transportation include: establishing an overland low-boom standard; reducing sonic boom and airport community noise; minimizing the impact of high-altitude emissions, and substantially improving efficiency. NASA's strategy is to first focus on the sonic boom standard issue. Based on successfully achieving a regulatory standard and initial industry innovation, NASA will then evaluate the potential for achieving the next set of environmental challenges in partnership with the aviation community.

The critical research issue for this Strategic Thrust is to determine if emerging supersonic aircraft technologies will support the elimination of today's prohibition of overland supersonic flight by reducing sonic boom to a publicly-acceptable level.

Thrust Description

The goal of this effort is to enable future supersonic vehicles to operate overland using criteria for acceptable sonic boom noise levels and accurate validated analysis tools for low-boom design and advanced configurations.

Table 5. Summary of Level 3 Outcomes for Thrust 15.2

Level 1		
15.0 Aeronautics	Strategic Objective:	Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan).
Level 2 - Thrust Name		
15.2 Innovation in Commercial Supersonic Aircraft	Thrust Description:	Provide low-boom standard, cruise efficiency, and noise reduction technologies that could lead to commercial supersonic flight over land.
Level 3 - Outcome Name		
15.2.1 Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise	Outcome Description:	Over the next decade (2015-2025), research will focus on overcoming the adverse impact of sonic boom in order to alleviate public concern and environmental impacts. Success in this research will enable the return of civil supersonic service that was abandoned in 2003, while expanding those services in terms of range and efficiency.
	Research Theme(s):	1) Understanding and Measuring Community Response to Sonic Booms - Research, development, and application of validated methodologies for a field study of community response to enable the development of overland sonic boom standards. 2) Integrated Design Solutions for Revolutionary High-Speed Aircraft - Research and development of validated analysis tools and technologies that enable the low sonic boom design of supersonic aircraft.
	Benefits:	Provides criteria and technology for future overland supersonic flight.
15.2.2 Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports	Outcome Description:	In the subsequent decade (2025-2035), building on success in 2015-2025, research in the additional challenges of landing and take-off noise, high altitude emissions, and fuel efficiency will enable affordable, low-boom, low-noise, and low-emission supersonic transportation accessible to a broader range of the traveling public. Into the future, Introduction of supersonic civil air transportation in 2025-2035 will provide the impetus for further research and development that can ultimately yield additional benefits for air travelers, the U.S. economy, and global connectivity.
	Research Theme(s):	Minimize airport community noise impact of high speed aircraft - Research and development of validated analysis tools and technologies to enable low airport noise propulsion systems design for supersonic aircraft.
	Benefits:	Provides validated analysis tools for advanced supersonic technologies.

TA 15.2.1 Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise

Since commercial overland supersonic flight is currently prohibited, NASA's strategy for the near term (2015-2025) is to focus on establishing a standard for allowable sonic boom. Because international routes comprise a major share of the potential market for supersonic service, NASA will work with the international standards community to define sonic boom levels that will be acceptable to the public. In parallel, NASA will develop analysis tools and technologies intended to enable the design and development of supersonic aircraft with low sonic boom.

Technical Challenges

The first outcome of this area is to provide overland sonic boom criteria for future supersonic vehicles. These criteria will be based on validated field study methodology, including indoor and outdoor noise metrics, survey tools, and test protocols performed with a demonstrator aircraft by 2020. The second outcome is to validate as ready for application in a flight demonstrator by 2025 the tools and technologies that enable the design of supersonic aircraft capable of reducing sonic boom noise to 80 perceived level decibels (PLdB).

Benefits of Technology

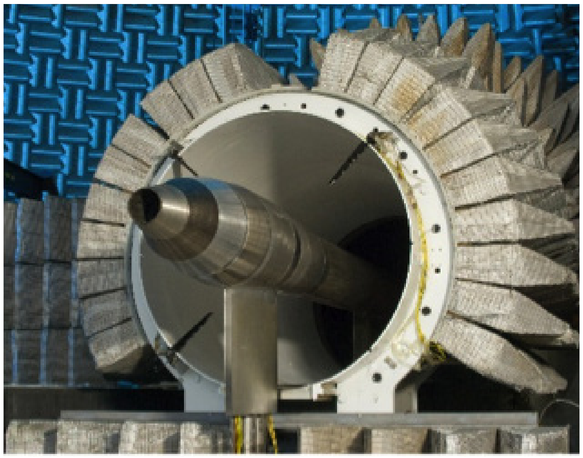
These two items are critical to enabling overland supersonic flight and providing U.S. leadership in low-boom supersonic technology.

Table 6. TA 15.2.1 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.2.1.1	Develop Methodologies and Metrics for Sonic Boom Community Response	Develop and validate a field study methodology including indoor and outdoor noise metrics, survey tools, and test protocols to support community studies with a demonstrator aircraft.
15.2.1.2	Develop Low Sonic Boom Design Tools	Develop tools and technologies enabling the design of supersonic aircraft that reduce sonic boom noise to 80 PLdB validated as ready for application in a flight demonstrator.

TA 15.2.2 Introduction of Affordable, Low-Boom, Low-Noise, Low-Emission Supersonic Transports

In the mid-term (2025-2035), following success in achieving a regulatory standard and initial innovation by the industry, NASA will evaluate the potential for addressing the environmental and efficiency challenges in partnership with the aviation community. Research outcomes in the future will depend on the evolution of the market and the prospects for technology solutions to increase efficiency, range, and environmental compatibility.



Acoustic test of a low-noise nozzle concept

Technical Challenges

The objective of this effort by 2035 is to enable the development and operation of affordable, low-boom, low-noise, and low-emission supersonic transports. This effort will develop design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 effective perceived noise level in decibels (EPNdB) less than International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) stage 4 demonstrated in ground test.

Benefits of Technology

Affordable, low-boom, low noise technology is vital for the development of future overland supersonic transports and to maintain the U.S. lead in advanced supersonic technologies.

Table 7. TA 15.2.2 Technical Challenge

TA	Technical Challenge Name	Description
15.2.2.1	Design and Develop Low-Noise Propulsion Tools and Concepts for Low-Boom Aircraft	Develop design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than ICAO and FAA stage 4 demonstrated in ground test.

TA 15.3: Ultra-Efficient Commercial Vehicles

The basic formula of commercial transport vehicles has not changed much in the past three decades. While incremental improvements have been made in structures and propulsion, the basic configuration of the commercial transport vehicle remains essentially the same. With global air traffic predicted to increase dramatically, aircraft of the future will need high vehicle efficiency, low environmental impact, and low community noise levels. NASA is pursuing low-weight structural design manufacture and maintenance, high-efficiency propulsion, high-efficiency aircraft configurations, and low-noise vehicle design to achieve this goal. The Ultra-Efficient Commercial Transport Strategic Thrust will develop technologies for revolutionary configurations, structural weight reduction, efficient propulsion, noise reduction, emission reduction, and improved composite fabrication for commercial aircraft of the future.

Thrust Description

NASA's work in future fixed wing vehicles supports reductions in carbon emissions by achieving a 1.5 percent average annual fuel efficiency improvement between 2010 and 2020, carbon-neutral growth from 2020 onward, and a 50 percent reduction in net emissions by 2050 compared to 2005 levels.

Table 8. Summary of Level 3 Outcomes for Thrust 15.3

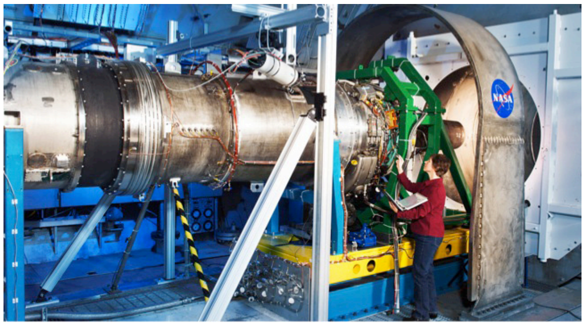
Level 1		
15.0 Aeronautics	Strategic Objective:	Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan).
Level 2 - Thrust Name		
15.3 Ultra-Efficient Commercial Vehicles	Thrust Description:	Pioneer technologies for future generations of commercial transports that simultaneously reduce noise, fuel use, and emissions.
Level 3 - Outcome Name		
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Outcome Description:	Over the next decade (2015-2025), community efforts will focus on maturing and incorporating emerging technology improvements for the next generation of aircraft.
	Research Theme(s):	1) Advanced Ultra-efficient Airframes - Research and development of tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction. 2) Advanced Ultra Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan Thrust Specific Fuel Consumption (TSFC), propulsion, noise, and emissions. 3) Advanced Airframe-Engine Integration - Research and development of innovative approaches and the supporting tools and technologies to reduce perceived noise and aircraft fuel burn through integrated airframe-engine concepts.
	Benefits:	Reduces noise, emissions, and fuel consumption for the next generation of commercial aircraft, minimizing the environmental impact as global air traffic increases, while maintaining safety.

Table 8. Summary of Level 3 Outcomes for Thrust 15.3 - Continued

Level 3 - Outcome Name		
15.3.2 Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035	Outcome Description:	In the mid-term decade (2025-2035), new transport-class vehicles will achieve desired levels of efficiency and environmental compatibility. Concurrently, new vertical lift designs will achieve improved levels of noise, efficiency, and environmental compatibility.
	Research Theme(s):	Clean and Efficient Rotorcraft Propulsion - Demonstration and maturation of engine and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalties.
	Benefits:	Reduces noise and fuel consumption for the next generations of vertical lift aircraft as well as minimizing the community environmental impact as vertical lift air traffic increases in the future.
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035	Outcome Description:	Advanced transport vehicles will approach efficiency and environmental compatibility desired for this timeframe. Further in the future, new transports will achieve higher levels of efficiency and environmental performance.
	Research Theme(s):	1) Advanced Ultra-efficient Airframes - Research and development of tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction. 2) Advanced Component Noise Reduction - Improvements in propulsion, airframe, and other subsystem components to achieve noise reduction. 3) Advanced Ultra Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan Thrust Specific Fuel Consumption (TSFC), propulsion, noise, and emissions. 4) Advanced Airframe-Engine Integration - Research and development of innovative approaches and the supporting tools and technologies to reduce perceived noise and aircraft fuel burn through integrated airframe-engine concepts.
	Benefits:	Reduces noise, emissions, and fuel consumption for the next generation of commercial aircraft.

TA 15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

Current commercial vehicles are using traditional configuration “tube and wings” that have been in use since the beginning of commercial air activities. While significant improvement in noise, emissions, and fuel consumption have been made, the process has been evolutionary since the 1960s. This work will dramatically reduce noise, emissions, and fuel consumption through revolutionary advances in active and passive flow for drag reduction, advanced composite construction for weight reduction and improved manufacturing, engine and combustor design for reduced emissions, and airframe configuration engine integration for reduced noise, while maintaining safety.



Engine Icing Test

Technical Challenges

By 2025, these technologies will deliver a 50 percent reduction in energy consumption, 75 percent reduction in landing and take-off nitrogen oxides (NOx), and noise reductions of 42 EPNdB from 2005 best practices.

Benefits of Technology

This technology will reduce noise, emissions, and fuel consumption for the next generation of commercial aircraft, minimizing the environmental impact as global air traffic increases while maintaining safety.

Table 9. TA 15.3.1 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.3.1.1	Demonstrate Innovative Flow Control	Demonstrate drag reduction of 8 percent, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, without significant penalties in weight, noise, or operational complexity.
15.3.1.2	High-Temperature Turbine Engine Materials	Develop high-temperature (2,700° F) materials for turbine engines that enable a 6 percent reduction in fuel burn for commercial aircraft, compared to SOA materials.
15.3.1.3	Demonstrate Advanced Composites for Weight Reduction	Demonstrate weight reduction of 10 percent compared to SOA composites, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while enabling lower drag airframes and maintaining safety margins at the aircraft system level.
15.3.1.4	Demonstrate Advanced Ultra High Bypass (UHB) Engine Designs for Specific Fuel Consumption and Noise Reduction	Demonstrate UHB efficiency improvements to achieve 15 percent TSFC reduction, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while reducing engine system noise and minimizing weight, drag, NOx, and integration penalties at AC system level.
15.3.1.5	Demonstrate Advanced Combustor Designs for Reduction in Nitrogen Oxides (NOx)	Demonstrate reductions of landing and take-off NOx by 75 percent and cruise NOx by 70 percent from Committee on Aviation Environmental Protection (CAEP6), while minimizing the impact on fuel burn at the aircraft system level, without penalties in stability and durability of the engine.
15.3.1.6	Demonstrate Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction	Demonstrate reduced component noise signatures leading to a 42 EPNdB ICAO and FAA stage 4 noise margin for the aircraft system while minimizing weight and integration penalties to enable 50 percent fuel burn reduction at the aircraft system level.
15.3.1.7	40% Reduction in Computational Fluid Dynamics (CFD) Error for Aeronautical Flows	Identify and downselect critical turbulence, transition, and numerical method technologies for 40 percent reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows and shock-boundary layer interactions on state of the art high performance computing hardware.

TA 15.3.2 Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035

Current rotary wing vehicles are using traditional designs that have existed for decades. These designs have not been optimized for noise or efficiency and depend on traditional drive system technologies. In this area, NASA will demonstrate and mature engine and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalty at reduced noise levels.

Advanced Vertical Lift Concept

Technical Challenges

NASA will demonstrate and mature engine and drive system concepts, such as variable speed power turbines (VSPT), and two-speed drive systems to enable 14 decibel (dB) perceived noise level reduction, and 60 percent reduction in fuel consumption over 2005 levels.

Benefits of Technology

This technology will reduce noise and fuel consumption for the next generation of vertical lift aircraft, minimizing the community environmental impact as vertical lift air traffic increases in the future.

Table 10. TA 15.3.2 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.3.2.1	Demonstrate Variable Speed Power Turbine (VSPT) Concept	Demonstrate 50 percent improvement in efficient operational capability using a variable speed power turbine concept.
15.3.2.2	Demonstrate Two Speed Drive System	Demonstrate two-speed drive system with less than 2 percent power loss while maintaining current power-to-weight ratios.

TA 15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035

As mentioned before, current commercial vehicles are using traditional configurations that have been in use since the beginning of commercial air activities. This work furthers the 2035 work to dramatically reduce noise, emissions, fuel consumption, and improve manufacturing. Revolutionary advances in optimal aspect ratio design, composite construction, advanced engine and combustor design, and advanced configurations will open the path to the needed efficient aircraft of tomorrow.

Technical Challenges

This will be done through increased optimal wing aspect ratio, advanced composite manufacturing analysis and testing, advanced engine and combustor design, and advanced engine boundary layer ingestion. In the future, these technologies could deliver a 100 percent improvement in optimal wing aspect ratio, landing and take-off (LTO) NOx reductions from CAEP standards of 80 percent, fuel/energy consumption reduction of 60 percent, composite design and inspection time reduction of 30 percent, and noise reductions of 52 dB cumulative from 2005 best practices.

Benefits of Technology

This technology will further reduce noise, emissions, and fuel consumption for the next generation of commercial aircraft, as well as improve the composite structure manufacturing process.

Table 11. TA 15.3.3 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.3.3.1	Enable an Increase in Optimal Aspect Ratio	Enable a 1.5X to 2X increase in the aspect ratio of a lightweight wing with safe flight control and structures (compared to 2005 best in class).
15.3.3.2	Reduce Composites Design and Testing Effort and Cycle Time	Develop analytical methods and rapid-design tools to reduce structural design cycle time and testing effort by 30 percent during development and certification.
15.3.3.3	Enable Rapid Inspection of Composites	Increase inspection throughput phases by 30 percent through development of quantitative and practical inspection methods, data management methods, models, and tools.
15.3.3.4	Streamline Composites Manufacturing	Streamline automated manufacturing technologies for better quality control, reduced defects, and fewer iterations to reach manufacturing certification.
15.3.3.5	Reduce Fan and High-Lift Noise	Reduce fan (lateral and flyover) and high-lift system (approach) noise on a component basis by 4 dB with minimal impact on weight and performance.
15.3.3.6	Enable Low Nitrogen Oxides (NOx) Fuel Flex Combustor - Propulsion	Reduce NOx emissions from fuel-flexible combustors to 80 percent below the CAEP6 standard with minimal impacts on weight, noise, or component life.
15.3.3.7	Enable Compact High Operating Pressure Ratio (OPR) Gas Generator	Enable reduced size/flow gas generators with 50+ OPR and disk/seal temperatures of 1,500° F with minimal impact on noise and component life.
15.3.3.8	Demonstrate Integrated Boundary Layer Ingestion (BLI) System	Achieve a vehicle-level net system benefit with a distortion-tolerant inlet/fan, boundary-layer ingesting propulsion system on a representative vehicle.

TA 15.4: Transition to Low-Carbon Propulsion

Nearly 100 percent of the fuel being used in aviation operations today is derived from petroleum, although progress is being made toward adoption of alternative fuels. The commercial supply of energy and its process stability remain a critical business concern; fuel currently represents the largest operating cost for the U.S. airlines. Engines have improved performance, and modern large commercial aircraft turbine engines are now designed with overall engine efficiency around 30 percent for high-bypass turbofans. NASA's challenge is to enable the use of readily-available, low-carbon fuels for traditional propulsion systems and investigate alternative propulsion systems for the aircraft of the future.

The Transition to Low-Carbon Propulsion Strategic Thrust will examine the transition of conventional aircraft propulsion systems to non-petroleum-based fuels, such as bio-fuels. This area will also examine alternative propulsion systems, such as hybrid electric systems, by improving the power density of electric aircraft motors and improving the efficiency of combustors used in onboard electricity generation. The application of these technologies will decrease the environmental impact of future commercial aircraft.

Thrust Description

NASA has two major areas of technical focus for achieving low-carbon propulsion. The first is on characterizing alternative fuels, in partnership with the aviation community, to develop a suite of certified, commercially-available drop-in alternative fuels to lower the carbon use of standard turbofan engines in the near term. The second technical focus area is the exploration of new alternative propulsion systems, from hybrid-electric to fully electric propulsion, that can achieve very low or no carbon emissions. Feasibility studies will occur for smaller aircraft first, since energy and power requirements are lower. However, the overall vision is to achieve alternative propulsion systems for the large transport-class aircraft where the most energy is used. NASA will follow the progression from small-scale to large-scale aircraft to demonstrate and mature technology and deliver low-carbon and other key benefits in the near- to mid-term.

Table 12. Summary of Level 3 Outcomes for Thrust 15.4

Level 1		
15.0 Aeronautics	Strategic Objective:	Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan).
Level 2 - Thrust Name		
15.4 Transition to Low-Carbon Propulsion	Thrust Description:	Enable transition of industry to low-carbon fuels and alternative propulsion systems.
Level 3 - Outcome Name		
15.4.1 Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Outcome Description:	Over the next decade (2015-2025), a suite of lower life-cycle carbon jet fuels will become available for conventionally powered aircraft. At the same time, research will culminate in possible early applications in the general aviation sector of hybrid and fully electric propulsion systems.
	Research Theme(s):	Characterization and Integration of Alternative Fuels - Characterization of alternative fuels, combustor concepts, and their integration requirements.
	Benefits:	Enables more efficient use of alternative fuels in commercial aircraft by understanding plume effects, emissions and advanced combustor concepts.

Table 12. Summary of Level 3 Outcomes for Thrust 15.4 - Continued

Level 3 - Outcome Name		
15.4.2 Initial Introduction of Alternative Propulsion Systems	Outcome Description:	In the subsequent decade (2025-2035), extensive research on a selected range of propulsion systems and aircraft configurations will enable possible initial deployment of these technologies on regional jet or single-aisle transport aircraft.
	Research Theme(s):	Scalable Alternative Propulsion Systems - Research and development to enable hybrid propulsion concepts.
	Benefits:	Evaluates alternative propulsion systems using combinations of alternative fuels and electric propulsion to provide low-carbon, energy efficient small aircraft.

TA 15.4.1 Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems

In the near term (2015-2025), NASA will continue working with current partners to complete ongoing efforts to lower the emissions of aircraft that use conventional propulsion systems. This effort will include characterization of emissions of alternative fuels during all phases of flight. In addition, NASA will engage with the community to explore future options for low-carbon propulsion in order to define the technologies, benefits, and risks associated with candidate concepts for implementation in the future.

Technical Challenges

Currently, alternative commercial fuels consist of 50/50 blends of alternative fuels, such as Fischer-Tropsch, and Hydroprocessed Esters and Fatty Acids organic fuels, with standard jet fuel. These fuels are used with traditional engine combustor designs that are not optimized for emissions. Very limited emissions data exist on newly-certified fuels. No emissions data exists at cruise altitude conditions, and fuel effects on plume chemistry and contrails are not known. This effort will characterize emissions and plume effects of alternative fuels at various flight conditions. Alternative fuels will be used with advanced combustor designs to demonstrate improved NOx emissions.

Benefits of Technology

By understanding the plume effects and emissions, this work will enable more efficient use of alternative fuels in commercial aircraft.

Table 13. TA 15.4.1 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.4.1.1	Characterize Alternative Fuel Emissions at Cruise	Conduct fundamental characterization of a representative range of alternative fuel emissions at cruise altitude.
15.4.1.2	Demonstrate Advanced Combustor Design for Nitrogen Oxides Reduction	Demonstrate reductions of LTO NOx by 75 percent from CAEP6 and cruise NOx by 70 percent, while minimizing the impact on fuel burn at the aircraft system level, without penalties in stability and durability of the engine system.
15.4.1.3	Enable Low-Nitrogen Oxides (NOx) Fuel Flexible Combustor - Alternative Fuels	Reduce NOx emissions from fuel-flexible combustors to 80 percent below the CAEP6 standard with minimal impacts on weight, noise, or component life.

TA 15.4.2 Initial Introduction of Alternative Propulsion Systems

In the mid term (2025-2035), NASA will take the lead in identifying, evaluating, and down-selecting various alternative propulsion systems and fuels. Hybrid-electric propulsion represents one candidate approach that NASA has studied, but more work is needed to identify and assess the full range of options, benefits, and hurdles to implementation. Throughout the process, NASA will conduct comparative analyses of potential technology advances offering transformative propulsion architectures that might further reduce the environmental impacts of aviation.

Technical Challenges

Extensive research on the selected range of alternative systems and fuels will enable initial deployment of these technologies on comparatively small aircraft. Alternative fuel use with high overall pressure ratio combustor design will be examined for future hybrid-electric systems. In addition to the combustor investigation, alternative propulsion systems, such as high-power-density electric motors, will be researched for smaller aircraft. An initial goal would be to develop a 1 megawatt (MW) class non-cryogenic motor with increased power density compared to the SOA by reducing material weight, increasing thermal conductivity of electrical insulation material, increasing conductivity of coils, and increasing temperature of power electronics.

Benefits of Technology

This work will evaluate alternative propulsion systems using combinations of alternative fuels and electric propulsion to provide low-carbon, energy-efficient small aircraft.

Table 14. TA 15.4.2 Technical Challenge

TA	Technical Challenge Name	Description
15.4.2.1	Establish One or More Gas-Electric Propulsion Concepts	Establish one or more viable concepts for 5-10 MW hybrid gas-electric propulsion system for a commercial transport aircraft.

TA 15.5: Real-Time System-Wide Safety Assurance

Currently, air traffic system-wide safety assurance is a combination of techniques using manual and semi-automated tools to get a system-wide context for safety threat identification. Aviation system-wide safety assurance is derived from recent advances in sensing and collecting a broad and varied set of operational data. This data is then analyzed by subject matter experts to reveal systemic safety causal factors that form the basis for designing and implementing mitigations. Data sharing and mining for events is a difficult, manual process with very little automation. Pilot distinction between nominal and off-nominal conditions is done through pilot perception and training. Currently, there is no ability for event correlation across large, heterogeneous, distributed systems. Precursors to aviation safety incidents are investigated on an as-needed basis and done by manual data mining.

This Strategic Thrust addresses the need for a continuum of information, analysis, and assessment that supports awareness and corrective action at levels appropriate to the potential threat to ongoing system-wide safety. Development of a real-time, system-wide safety assurance system will necessitate automating safety assurance of air transportation system components, integrating component-level systems, and reducing the safety assurance cycle time until real-time safety assurance is achieved at the system-of-systems level. This Strategic Thrust will combine ATS and onboard vehicle technologies as well as ATS automated data mining capability into a system for continuous safety monitoring and threat prediction. This system will maintain or exceed the current level of air traffic safety well into the future, accommodating global increases in air travel.

Thrust Description

NASA will advance the access to sensitive data, as well as techniques for anomalous event discovery, alerting, and mitigation. This area will leverage ongoing advancements in sensing, computation, communications, and analytics to provide integrated, system-wide safety assurance. The development of system-wide safety assurance will be done in a spiral fashion, with the gradual development of three technology areas in an incremental way as the integrated safety assurance function times evolve from days to hours to real-time.

Table 15. Summary of Level 3 Outcomes for Thrust 15.5

Level 1		
15.0 Aeronautics	Strategic Objective:	Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan).
Level 2 - Thrust Name		
15.5 Real-Time System-Wide Safety Assurance	Thrust Description:	Develop tools for use in a prototype of an integrated safety monitoring and assurance system that detects, predicts, and prevents safety problems in real time.
Level 3 - Outcome Name		
15.5.1 Introduction of Advanced Safety Assurance Tools	Outcome Description:	Over the next decade (2015-2025), continued development of safety tools such as data mining and analysis, prognostics, real-time system assurance techniques, and safety risk modeling will improve the ability to gain insights and develop solutions. Taking advantage of the increasing availability of aviation system data, identification of safety issues will focus on scaling currently available data mining technologies to process system-wide data. Increased speed and accuracy of analysis tools will support progress toward real-time identification of precursors to emerging safety issues.
	Research Theme(s):	1) System-wide Data Analysis for Understanding Safety Events – Technical approaches for integrating sensitive data from heterogeneous sources to build base models of nominal and off-nominal system performance and improve accuracy of detection and prediction tools. 2) Improved Performance of Detection, Analysis and Prognostic Tools – Increased speed and scaling of tools to enable rapid detection safety threats in large, heterogeneous data sets as they arise. 3) Integrated Threat Prognosis, Alerting, and Guidance – Architecture for integration of scaled, automated methods for threat alerting, prognosis and guidance to improve mitigation strategies; simulation tools for real-time operational evaluation. 4) Techniques for Real-time Safety Assurance - Advances in verification techniques to be applied during deployment and execution of systems to monitors that can efficiently analyze risks and potential solutions efficiently.
	Benefits:	Increases system safety of the NextGen future ATS by providing system-wide integrated methods to detect safety incident precursors and increase pilot situational awareness.
15.5.2 An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring	Outcome Description:	In the subsequent decade (2025-2035), integration of analysis into a live virtual simulation of the National Airspace System will provide a comprehensive picture of system health and facilitate coordination of mitigation strategies. This capability will improve safety assurance through earlier detection of trends and risks system-wide. More highly automated safety assessments will enable continuous safety assurance, and an automated system will evolve over the decade to enable near-real-time assessments as confidence increases in regularly validated system judgments.
	Research Theme(s):	1) System-wide Data Analysis for Understanding Safety Events – Technical approaches for integrating sensitive data from heterogeneous sources to build base models of nominal and off-nominal system performance and improve accuracy of detection and prediction tools. 2) Improved Performance of Detection, Analysis and Prognostic Tools – Increased speed and scaling of tools to enable rapid detection safety threats in large, heterogeneous data sets as they arise. 3) Integrated Threat Prognosis, Alerting, and Guidance – Architecture for integration of scaled, automated methods for threat alerting, prognosis and guidance to improve mitigation strategies; simulation tools for real-time operational evaluation. 4) Techniques for Real-time Safety Assurance - Advances in verification techniques to be applied during deployment and execution of systems to monitors that can efficiently analyze risks and potential solutions efficiently.
	Benefits:	Near-real-time discovery and corrective actions of safety threats.

Table 15. Summary of Level 3 Outcomes for Thrust 15.5 - Continued

Level 3 - Outcome Name		
15.5.3 Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System	Outcome Description:	In the future, the automated safety assurance system will become integrated with real-time operations to help create an aviation system that exhibits the properties of self-protection and self-healing. In the more distant future, human operators and autonomous systems will collaborate to ensure an optimal mix of corrective actions — from immediate operational adjustments to longer-term system and infrastructure changes — in order to minimize safety risks. Work will culminate in an integrated demonstration of a prototype real-time system-wide safety assurance system.
	Research Theme(s):	1) System-wide Data Analysis for Understanding Safety Events – Technical approaches for integrating sensitive data from heterogeneous sources to build base models of nominal and off-nominal system performance and improve accuracy of detection and prediction tools. 2) Improved Performance of Detection, Analysis and Prognostic Tools – Increased speed and scaling of tools to enable rapid detection safety threats in large, heterogeneous data sets as they arise. 3) Integrated Threat Prognosis, Alerting, and Guidance – Architecture for integration of scaled, automated methods for threat alerting, prognosis and guidance to improve mitigation strategies; simulation tools for real-time operational evaluation. 4) Techniques for Real-time Safety Assurance - Advances in verification techniques to be applied during deployment and execution of systems to monitors that can efficiently analyze risks and potential solutions efficiently.
	Benefits:	Provides technology to enable a self-protecting and self-healing air traffic system.

15.5.1 Introduction of Advanced Safety Assurance Tools

Over the next decade (2015-2025), continued development of safety tools, such as data mining and analysis, prognostics, real-time system assurance techniques, and safety risk modeling, will improve the ability to gain insights and develop solutions. Taking advantage of the increasing availability of aviation system data, identification of safety issues will focus on scaling currently-available data mining technologies to process system-wide data. Increased speed and accuracy of analysis tools will support progress toward real-time identification of precursors to emerging safety issues.

Technical Challenges

This effort will begin the development of the technologies listed under 15.5.1-3. This activity will advance the area of data mining across heterogeneous data sets for improved discovery of precursors to aviation safety incidents. It will demonstrate a new class of prognostic algorithms that are verifiable, thus removing obstacles to their certification and enabling their safety benefits. This work will dramatically reduce the time to analyze, identify, and mitigate safety risks from months down to perhaps a day.

Benefits of Technology

Increases system safety of the NextGen future ATS by providing system-wide, integrated methods to detect safety incident precursors and increase pilot situational awareness.

15.5.2 An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring

In the subsequent decade (2025-2035), integration of analyses into a live, virtual simulation of the NAS will provide a comprehensive picture of system health and facilitate coordination of mitigation strategies. This capability will improve safety assurance through earlier detection of system-wide trends and risks. More highly automated safety assessments will enable continuous safety assurance, and an automated system will evolve over the decade to enable near-real-time assessments as confidence increases in regularly-validated system judgments.

Technical Challenges

This Level 3 area will further develop all of the technologies under 15.5.1-3 to the next level beyond 15.5.1. This work will integrate advanced tools into a highly-automated safety assurance system that will enable continuous, system-wide safety assessment. This continous monitoring will lead to rapid identification of safety issues and corrective actions that will reduce the aircraft accident rate in all categories. Such an automated system will evolve through implementation in the NextGen virtual development environment.

Benefits of Technology

Reduces aircraft accident rate in all categories.

15.5.3 Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System

In the future, the automated safety assurance system will become integrated with real-time operations to help create an aviation system that exhibits the properties of self-protection and self-healing. In the more distant future, human operators and autonomous systems will collaborate to ensure an optimal mix of corrective actions—from immediate operational adjustments to longer-term system and infrastructure changes—in order to minimize safety risks. Work will culminate in an integrated demonstration of a prototype real-time, system-wide safety assurance system.

Technical Challenges

This Level 3 area will advance system-wide safety assurance to the self-protecting level. It will develop capabilities that allow pilots to make more effective decisions in complex situations posed by most important current and emerging risk areas, such as airplane state awareness within the NextGen ATS. An integrated vehicle health assurance capability will be developed that incorporates sensing and diagnostics for airframe, engine, and wiring systems.

Benefits of Technology

This technology will increase the system safety of the NextGen future ATS by providing system-wide, integrated methods to detect safety incident precursors and increase pilot situational awareness. Current air traffic safety levels will be maintained or improved with the increased volume of global air traffic.

Table 16. TA 15.5.1-3 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.5.1-3.1	Automate Discovery of Precursors	Enable automated discovery of precursors to safety incidents.
15.5.1-3.2	Prognostic Algorithm Design for Safety	Develop prognostic algorithms to improve identification and mitigation of safety threats.

TA 15.6: Enable Assured Machine Autonomy for Aviation

Recent interest in using the UAS has escalated rapidly with broad interest across a wide range of Federal and non-Federal organizations. Because of this, UAS access to the NAS has become a priority. Current processes for UAS flight clearance in the NAS include the application for an experimental airworthiness certificate or a Certificate of Operation, which can typically take weeks or months to complete. To ensure safe flight operations of UAS, procedures for certification, licensing, training, inspection, maintenance, and operation are needed. This will ensure UAS integration into the NAS without causing delays, reducing capacity, or compromising safety in the air or on the ground.

This Strategic Thrust intends to research the design and operation of autonomous systems, including issues associated with verification and validation (V&V), certification, trusted operations, and human-machine and machine-machine teaming. The goal is to achieve UAS operations in the NAS and develop key technologies and standards needed for future vehicles with additional automation and autonomy.

Thrust Description

NASA's focus is to research the design and operation of autonomous systems, including issues associated with Minimum Operating Performance Standards (MOPS), human-machine and machine-machine teaming, V&V, and certification. In the near-, mid- and long-terms, NASA will focus on outcomes that enable UAS operations in the NAS. NASA will combine a long-term focus on solving foundational problems associated with the design and analysis of autonomous systems, with near-term spiral development on specific autonomy applications.

Table 17. Summary of Level 3 Outcomes for Thrust 15.6

Level 1		
15.0 Aeronautics	Strategic Objective:	Enable a revolutionary transformation for safe and sustainable U.S. and global aviation by advancing aeronautics research (see NASA's 2014 Strategic Plan).
Level 2 - Thrust Name		
15.6 Enable Assured Machine Autonomy for Aviation	Thrust Description:	Enable the utilization of higher levels of automation and autonomy across the aviation system including routine UAS presence in the NAS.
Level 3 - Outcome Name		
15.6.1 Initial Autonomy Applications	Outcome Description:	Research for the near-term (2015-2025) will help the initial integration of UAS capabilities into the NAS. Through community-wide collaboration, NASA will also identify and investigate opportunities for exploiting autonomous systems within the near-term aviation infrastructure. For example, research will address growing community interest in enabling the operation of small, highly automated vehicles within specially designated areas, as well as integration with more conventional aviation operations where appropriate. Other early applications of autonomy, such as autonomous emergency landing systems, will improve system performance and safety. Research for this timeframe will help to define the benefits and risks of potential autonomous systems, facilitating selection of the most appropriate candidates for focused research and application. Evolution of the test infrastructure will support critical exploration and validation activities.
	Research Theme(s):	1) UAS Integration - Airspace integration procedures and performance standards to enable UAS integration in the air transportation system. 2) Validation, Verification, Testing, and Evaluation - Application of assurance technologies to validate performance of autonomous systems in a variety of known (i.e. conceivable) operational scenarios; extension of traditional verification and validation techniques to ensure trust and confidence in the performance of machine learning, and sense-making autonomy functions capable of adapting to conditions of the unknown type.
	Benefits:	Establishes critical criteria for operating UAS in the NAS, as well as validating operational techniques.
Level 3 - Outcome Name		
15.6.2 Ability to Fully Certify and Trust Autonomous Systems for NAS Operations	Outcome Description:	In the far-term, NASA research will help to enable the widespread use of autonomy across a broad range of NAS functions. Development of techniques for verification, validation, and systems certification of complex, joint human-machine cognitive systems will support efforts to establish trust in autonomous systems and allow for eventual certification of the full range of autonomous operations.
	Research Theme(s):	1) Validation, Verification, Testing, and Evaluation - Application of assurance technologies to validate performance of autonomous systems in a variety of known (i.e. conceivable) operational scenarios; extension of traditional verification and validation techniques to ensure trust and confidence in the performance of machine learning, and sense-making autonomy functions capable of adapting to conditions of the unknown type. 2) Design and Analysis of Autonomous Systems - Development of core automation for supporting specific autonomy operational needs in functional areas such as navigation, communication, surveillance, and robotics, and design of architectures for integration of technologies into an autonomous system. 3) Autonomous Planning, Scheduling, and Decision Making - Development and application of advanced cognitive computing architectures and sensory technologies for reasoning and decision making, and capabilities for engaging unknown unknowns in the operational environment as part of human-machine cognitive systems. 4) Vehicle Control, Health Management, Adaptation, and Multivehicle - Application of autonomy to assist human-in-vehicle operations and expanding vehicle health management capabilities.
	Benefits:	Provides cost effective certified flight critical software that will assist in the implementation plan for the NextGen NAS system.

TA 15.6.1 Initial Autonomy Applications

Research for the near term (2015-2025) will help the initial integration of UAS capabilities into the NAS. Through community-wide collaboration, NASA will also identify and investigate opportunities for exploiting autonomous systems within the near-term aviation infrastructure. For example, research will address growing community interest in enabling the operation of small, highly-automated vehicles within specially-designated areas, as well as integration with more conventional aviation operations where appropriate. Other early applications of autonomy, such as autonomous emergency landing systems, will improve system performance and safety. Research for this timeframe will help define the benefits and risks of potential autonomous systems, facilitating selection of the most appropriate candidates for focused research and application. Evolution of the test infrastructure will support critical exploration and validation activities.

Areas of Interest

This effort will further develop a relevant test environment and use it to validate UAS minimum operating performance standards (MOPS) for sense and avoid (SAA), command and control (C2), human systems integration (HSI), and ground control stations (GCS). This will involve developing hardware, flight testing, and reporting to validate MOPS using UAS in the NAS test scenarios.

Benefits of Areas of Interest

This work will use a series of simulation and test data to establish critical criteria for operating UAS in the NAS, as well as validating operational techniques. The criteria will be used to provide initial performance standards for UAS in the areas of sense and avoid, terrestrial command and control, human systems integration, and certification of UAS for integration into the NAS.

TA 15.6.2 Ability to Fully Certify and Trust Autonomous Systems for NAS Operations

In the far term, NASA research will help to enable the widespread use of autonomy across a broad range of NAS functions. Development of techniques for verification, validation, and systems certification of complex, joint human-machine cognitive systems will support efforts to establish trust in autonomous systems and allow for eventual certification of the full range of autonomous operations.

Technical Challenges

This effort aims to provide an initial tool suite that expedites the certification of flight-critical software and lowers the software life cycle costs across complex NextGen systems. This effort will demonstrate the scalability of software assurance tools to larger case studies used in industry and ensure viability of compositional reasoning for assessing interactions in large, complex systems.

Benefits of Technology

Cost effective, certified, flight-critical software will be central to the implementation plan for the NextGen NAS system. This tool suite will fill a critical gap in life-cycle development of complex systems for NextGen by developing V&V techniques that establish justifiable confidence that new technologies envisioned for NextGen are as safe as (or safer than) the current system and provide a cost-effective basis for assurance and certification of complex civil aviation systems.

Table 18. TA 15.6.2 Technical Challenges – not in priority order

TA	Technical Challenge Name	Description
15.6.2.1	Assurance of Flight Critical Systems	Develop verification and validation techniques to instill confidence that new technologies are as safe as (or safer than) the current system and provide a cost-effective basis for assurance and certification of complex civil aviation systems.

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Appendix

Acronyms

ACES	Airspace Concept Evaluation System
AFP	Automated Fiber Placement
AFR	Autonomous Flight Rules
AOP	Airborne Operations Planner
ARMD	Aeronautics Research Mission Directorate
ATM	Air Traffic Management
ATOL	Air Traffic Operations Lab
ATS	Air Transportation System
BLI	Boundary Layer Ingestion
C2	Command and Control
CAEP	Committee on Aviation Environmental Protection
CFD	Computational Fluid Dynamics
CMC	Ceramic Matrix Composite
CMS	Controller Managed Spacing
DRM	Design Reference Mission
DWR	Dynamic Weather Routes
FAA	Federal Aviation Administration
FACET	Future ATM Concepts Evaluation Tool
FIM	Flight deck Interval Management
GCS	Ground Control Station
HEFA	Hydroprocessed Esters and Fatty Acids
HSI	Human Systems Integration
HWB	Hybrid Wing Body
ICAO	International Civil Aviation Organization
ITP	In-Trail Procedure
LOC	Loss of Control
LTO	Landing and Take-Off
LVC-DE	Live Virtual Constructive-Distributed Environment
MOPS	Minimum Operating Performance Standards
N+2	N+2 levels of aircraft performance (2025-2035)
N+3, N+4	N+3, N+4 levels of aircraft performance (> 2035)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NDI	Non-Destructive Inspection
NOx	Nitrogen Oxides
OCT	Office of the Chief Technologist

OPR	Operating Pressure Ratio
PAI	Propulsion Airframe Integration
PDRC	Precision Departure Release Capability
PTM	Pairwise Trajectory Management
SAA	Sense and Avoid
SARDA	Spot and Runway Departure Advisor
SIP	Strategic Implementation Plan
SMA	Surface Management Advisor
SMART NAS	Shadow Mode Assessment using Realistic Technologies for the NAS
SMS	Surface Management System
SOA	State Of the Art
TA	Technology Area
TABS	Technology Area Breakdown Structure
TASAR	Traffic Aware Strategic Aircrew Requests
TBO	Trajectory-Based Operations
TMA	Traffic Management Advisor
TRL	Technology Readiness Level
TSAFE	Tactical Separation Assured Flight Environment
TSFC	Thrust Specific Fuel Consumption
TSS	Terminal Sequencing and Spacing
UAS	Unmanned Aircraft System
UHB	Ultra High Bypass
U.S.	United States
VSPT	Variable Speed Power Turbine
V&V	Verification and Validation

Abbreviations and Units

Abbreviation	Definition
%	Percent
dB	Decibels
EPNdB	Effective perceived noise level in decibels
F	Fahrenheit
Hp	Horsepower
lb	Pound
Min	Minutes
MW	Megawatt
NOx	Nitrogen Oxides
PLdB	Perceived decibel level

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Technology Candidate Snapshots

15.1 Safe, Efficient Growth in Global Aviation
15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains

15.1.1.1 Increase Throughput

TECHNICAL CHALLENGE

Technical Challenge Description: Increase arrival throughput while maintaining safety, using integrated aircraft-based and ground-based automation technologies.

Research Theme: Advanced Operational Concepts, Technologies, and Automation - The research and development of operational efficiency incorporating proactive safety risk management in operational domains.

Technical Challenge State of the Art: NextGen technologies being developed in human-in-the-loop simulations: Terminal Sequencing and Spacing (TSS); Flight deck Interval Management (FIM) used with Traffic Management Advisor with Terminal aMetering (TMA-TM); and Controller Managed Spacing (CMS) tools.

Parameter, Value:
Uninterrupted operations: 50%

TRL
6

Technical Challenge Performance Goal: Demonstration of increased arrival throughput using advanced techniques within a virtual simulation environment.

Parameter, Value:
Uninterrupted operations: 80%

TRL
7

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Successful integration of NASA-developed technologies – TSS, FIM, TMA-TM and CMS.

TECHNICAL WORK

Needed Capability: Efficient air traffic operations while maintaining system wide safety.

Capability Description: Increase air traffic operations throughput using aircraft-based and ground-based automation technologies.

State of the Practice: Air traffic management personnel use TMA to manually sequence and space arrivals into busy airports. The aircraft are largely passive participants and are unable to make use of the trajectory management tools, e.g., Flight Management System, onboard.

Parameter, Value:
Uninterrupted operations: 30%

Technology Outcome: Improved Efficiency and Hazard Reduction Within NextGen Operational Domains.

Parameter, Value:
Uninterrupted operations: 80%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: Improved Efficiency and Hazard Reduction within NextGen Operational Domains	Enabling	--	--	2025	6 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains

15.1.1.2 Increase Terminal Efficiencies

TECHNICAL CHALLENGE

Technical Challenge Description: Increase arrivals, departures, and surface operations efficiency while increasing overall throughput and reducing safety risks.

Research Theme: Advanced Operational Concepts, Technologies, and Automation - The research and development of operational efficiency incorporating proactive safety risk management in operational domains.

Technical Challenge State of the Art: New technologies being deployed in a simulation environment include: Integrated Arrival/ Departure/ Surface Operations using Spot and Runway Departure Advisor (SARDA), Terminal Tactical Separation Assured Flight Environment (TSAFE), and Precision Departure Release Capability (PRDC).

Parameter, Value: Delay reduction: 2 min/flt

TRL 4

Technical Challenge Performance Goal: Demonstrate increased air traffic system efficiency using advanced technology in a virtual simulated environment.

Parameter, Value: Delay reduction: 5 min/flt

TRL 7

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Successful integration of NASA-developed technologies – SARDA, TSAFE and PDRC.

TECHNICAL WORK

Needed Capability: Efficient surface operations.

Capability Description: Manage air traffic throughput using Integrated Arrival/Departure/Surface Operations tools.

State of the Practice: Air traffic controllers manually sequence surface operations using data from radar, Airport Surface Detection Equipment (ASDE-X), and visual identification. There is poor predictability of surface movements and scheduling due to extreme differences in carrier's/operator's procedures. Isolated technologies used throughout the country: Traffic Management Advisors (TMA); Surface Management System (SMS); Surface Management Advisor (SMA); Departure Route Planning system; and Surface Movement Guidance and Control System.

Parameter, Value: Delay reduction: 0 min/flt

Technology Outcome: Improved Efficiency and Hazard Reduction Within NextGen Operational Domains.

Parameter, Value: Delay reduction: 5 min/flt

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: Improved Efficiency and Hazard Reduction within NextGen Operational Domains	Enabling	--	--	2025	5 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains

15.1.1.3 Reduce Weather Delays and Risks

TECHNICAL CHALLENGE

Technical Challenge Description: Reduce weather-induced delays and safety risks by integrating weather forecasts and nowcasts with aircraft operations, traffic flow, and airspace management strategies.

Research Theme: Advanced Operational Concepts, Technologies, and Automation - The research and development of operational efficiency incorporating proactive safety risk management in operational domains.

Technical Challenge State of the Art: Simulations and light plane demonstrations of the following technologies: the Traffic Aware Strategic Aircrew Requests (TASAR) flight-deck software application uses information (including automatic dependent surveillance – broadcast (ADS-B)) and weather data to compute flight-optimizing, traffic, and weather compatible trajectory changes; the Airborne Operations Planner (AOP) provides safety-critical decision support to the flight crew for autonomously managing the en-route trajectory in the presence of traffic, weather, airspace hazards, and arrival flow management constraints; the Dynamic Weather Routes (DWR) is a search engine that continuously analyzes in-flight aircraft in en-route airspace to find time- and fuel-saving corrections to weather avoidance routes.

Parameter, Value:	TRL
En-route weather delay reduction: 9.5 minutes	2

Technical Challenge Performance Goal: Demonstrate reduced weather-induced delays using advanced techniques in a virtual simulated environment.

Parameter, Value:	TRL
En-route weather delay reduction: 6.2 minutes	6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Accurate weather forecasts.

TECHNICAL WORK

Needed Capability: Increased weather routing and mitigation of localized weather constraints of air traffic management systems.
Capability Description: Increase efficiency of weather routing in air traffic management systems by integrating probabilistic and deterministic weather information.

State of the Practice: Groups of aircraft are manually routed around forecast weather systems. Air traffic personnel advise the pilot of significant weather issues and recommend changes as required for the continued safe operation of the flight.

Parameter, Value:
En-route weather delay reduction: None

Technology Outcome: Improved Efficiency and Hazard Reduction Within NextGen Operational Domains.

Parameter, Value:
En-route weather delay: 5 minutes

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: Improved Efficiency and Hazard Reduction within NextGen Operational Domains	Enabling	--	--	2025	5 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains

15.1.1.4 Improve Efficiency of Oceanic Operations

TECHNICAL CHALLENGE

Technical Challenge Description: Safely increase oceanic airspace operational efficiency by integrating air and ground procedures and technologies that enable reduced-separation minima and optimized routes and reroutes.

Research Theme: Advanced Operational Concepts, Technologies, and Automation - The research and development of operational efficiency incorporating proactive safety risk management in operational domains.

Technical Challenge State of the Art: The following technologies are being implemented in simulations: Pairwise Trajectory Management (PTM), and state of the art constrained wind-optimal trajectory generation.

Parameter, Value:	TRL
Trans-oceanic delay reduction over current operations: 23 minutes	2

Technical Challenge Performance Goal: Demonstrate a reduction of trans-oceanic delay over current operations using a virtual simulated environment.

Parameter, Value:	TRL
Trans-oceanic delay reduction over current operations: 23 minutes	6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Automatic dependent surveillance – broadcast (ADS-B) OUT/IN equipped aircraft.

TECHNICAL WORK

Needed Capability: Increased efficiency of oceanic airspace management.

Capability Description: Increase efficiency of oceanic airspace traffic by integrating weather, scheduling, and trajectory management tools.

State of the Practice: Currently, Air Traffic Controllers rely on an automatic dependent surveillance – contract (ADS-C) message being downlinked via datalink to manually separate trans-oceanic routes. Isolated technologies being used are: Dynamic Ocean and Track System Plus used to develop constrained wind optimal routes in the Pacific Ocean, and In-Trail Procedure (ITP) that enables changes in procedural airspace to perform changes on a more frequent basis.

Parameter, Value:

Trans-oceanic delay reduction over current operations: 0 minutes

Technology Outcome: Improved Efficiency and Hazard Reduction Within NextGen Operational Domains.

Parameter, Value:

Trans-oceanic delay reduction over current operations: 23 minutes

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: Improved Efficiency and Hazard Reduction within NextGen Operational Domains	Enabling	--	--	2025	6 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.1 Improved Efficiency and Hazard Reduction within NextGen Operational Domains

15.1.1.5 Develop Methods for Real-Time Assessments of Overall Engine Health

TECHNICAL CHALLENGE

Technical Challenge Description: Develop and implement advanced systems for real-time assessment of overall aircraft engine health.

Research Theme: Advanced Operational Concepts, Technologies, and Automation - The research and development of operational efficiency incorporating proactive safety risk management in operational domains.

Technical Challenge State of the Art: Engine health is monitored in flight with no prognostic capability. Maintenance is performed based on hours of engine usage and ground-based prognostics.

Parameter, Value:
Degradation is not automatically diagnosed

TRL 5

Technical Challenge Performance Goal: Real-time engine health assessment that will identify maintenance needed based on engine condition, rather than hours of engine usage.

Parameter, Value:
Degradation is automatically diagnosed

TRL 6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Engine sensor development.

TECHNICAL WORK

Needed Capability: Real-time engine health assessment that is prognostic for engine maintenance and operational hazards. **Capability Description:** Real-time prognistic engine health sensing capability that will provide early warning of engine damage and indicate maintenance based on engine condition, rather than engine operating hours.

State of the Practice: Prototype engine montoring has been demonstrated on testbed aircraft with little or no prognostic ability.

Parameter, Value:
No real-time prognostics

Technology Outcome: Improved Efficiency and Hazard Reduction Within NextGen Operational Domains.

Parameter, Value:
Real-time prognostics prevent malfunctions

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: Improved Efficiency and Hazard Reduction within NextGen Operational Domains	Enabling	--	--	2025	6 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.2 System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality

15.1.2.1 Reduce Occurrences of Crew Loss of Aircraft State Awareness

TECHNICAL CHALLENGE

Technical Challenge Description: Develop technologies and training processes that mitigate problems and contributing factors that lead to flight crew loss of aircraft state awareness.

Research Theme: Safety Management for Emergent Risks - Research and development of prognostic safety risk management solutions and concepts for emergent risks.

Technical Challenge State of the Art: Technologies currently in development increase pilot's ability to avoid, detect, and recover from adverse events that could otherwise result in accidents/incidents; reduce aircraft loss of control (LOC) events by understanding vehicle dynamics and providing the appropriate control response under multiple hazards; and enable development of robust human-automation systems by incorporating known limitations of human performance into analysis tools.

Parameter, Value:	TRL
Current performance of technologies will provide a baseline from which improvements will be measured.	3

Technical Challenge Performance Goal: Demonstrate increased pilot decision making capability using advanced simulation and aircraft systems systems in a simulated environment.

Parameter, Value:	TRL
One technology investigated provides 10 percent improvement in pilot decision-making capability.	5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Dependent upon specific technologies selected from among canidate technologies to address challenge.

TECHNICAL WORK

Needed Capability: Improved risk reduction in aircraft accident categories using advanced human factors and safety technology.
Capability Description: Incorporates known limitations of human performance into analysis tools to provide robust human-automation systems that will reduce risk in aircraft accident categories.

State of the Practice: ~70 percent accidents caused by spatial disorientation.

Parameter, Value:
Pilot decision making capability baseline for technology investigated.

Technology Outcome: System-wide Safety, Predictability, and Reliability Through Full NextGen Functionality.

Parameter, Value:
One technology investigated provides 10% improvement in pilot decision making capability

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality	Enabling	--	--	2035	6 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.2 System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality

15.1.2.2 Develop Virtual Environment Testing

TECHNICAL CHALLENGE

Technical Challenge Description: Develop a cloud-based, live, virtual, and constructive simulation of the National Airspace System (NAS) to perform integrated, multi-fidelity evaluations of future concepts, technologies, and architectures on the basis of system-level performance, safety, environmental impacts, and benefit.

Research Theme: Integrated Modeling, Simulation, and Testing - Development, validation, and application of advanced modeling, simulation, and testing capabilities to assess integrated, end-to-end NextGen trajectory-based operations functionality and seamless unmanned aircraft system (UAS) operations, as well as other future aviation system concepts and architectures.

Technical Challenge State of the Art: National airspace system (NAS)-wide and regional fast-time and real-time simulation tools: UAS developed Live Virtual Constructive-Distributed Environment (LVC-DE), Future ATM Concepts Evaluation Tool (FACET), Airspace Concept Evaluation System (ACES), AOL, Multi Aircraft Control System; Center Terminal Radar Control (TRACON) Automation System, and the Future Flight Central; and the Air Traffic Operations Lab (ATOL).

Parameter, Value:	TRL
Percent complete of virtual testing environment: 50%	2

Technical Challenge Performance Goal: Demonstrate elements of a NextGen Shadow Mode Assessment using Realistic Technologies for the NAS (SMART NAS) simulated environment using advanced NAS tools.

Parameter, Value:	TRL
Percent complete of vitual testing environment: 100%	5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Development of system architecture.

TECHNICAL WORK

Needed Capability: Validated demonstration environment for advanced SMART NAS concept demonstration.
Capability Description: Live virtual simulation environment that integrates and analyzes future concepts comprised of alternative systems and architectures.

State of the Practice: Elements of the virtual testing environment are in operation now with portions of integrated testing currently under way (integrated human-in-the-loop operations).

Parameter, Value:
Percent complete of virtual testing environment: 50%

Technology Outcome: System-wide Safety, Predictability, and Reliability Through Full NextGen Functionality

Parameter, Value:
Percent complete of virtual testing environment: 100%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality	Enabling	--	--	2035	8 years

15.1 Safe, Efficient Growth in Global Aviation
15.1.2 System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality

15.1.2.3 Optimize Air/Ground Functional Allocations

TECHNICAL CHALLENGE

Technical Challenge Description: Perform a design space exploration and make recommendations for the allocation of en route separation assurance functions to human operators and automation systems on the ground and in the air on the basis of system-level performance, safety, and economic values.

Research Theme: Airspace Operations Performance Requirements - Advanced research to develop performance requirements, functional allocation definitions and other critical data for integrated, end-to-end NextGen trajectory-based operations functionality, and seamless unmanned aircraft system (UAS) operations, as well as other future aviation system concepts and architectures.

Technical Challenge State of the Art: The following technologies have been implemented in simulation: Autonomous Operations Planner (AOP) and Autonomous Flight Rules (AFR).

Parameter, Value:	TRL
Recommendation of final air/ground functional allocations: 80 percent	1

Technical Challenge Performance Goal: Recommendations for the allocation of en-route separation assurance functions to human operators and automation systems on the ground and in the air.

Parameter, Value:	TRL
Recommendation of final air/ground functional allocations: 100 percent	2

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Improved separation assurance within the air transportation system (ATS).

Capability Description: Assure safe separation between flights using automated systems.

State of the Practice: Separation assurance is currently performed by an Air Traffic Controller, using radar position reports and automatic dependent surveillance – broadcast (ADS-B) in the domestic airspace; separation avoidance maneuvers are verbally relayed from the ground to the flight deck.

Parameter, Value:
Percent complete of final air/ground functional allocations: 10%

Technology Outcome: System-wide Safety, Predictability, and Reliability Through Full NextGen Functionality.

Parameter, Value:
Percent complete of final air/ground functional allocations: 100%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Safe, Efficient Growth in Global Aviation: System-Wide Safety, Predictability, and Reliability Through Full NextGen Functionality	Enabling	--	--	2035	6 years

15.2 Innovation in Commercial Supersonic Aircraft
15.2.1 Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise

15.2.1.1 Develop Methodologies and Metrics for Sonic Boom Community Response

TECHNICAL CHALLENGE

Technical Challenge Description: Develop and validate a field study methodology including indoor and outdoor noise metrics, survey tools, and test protocols to support community studies with a demonstrator aircraft.

Research Theme: Understanding and Measuring Community Response to Sonic Booms - Research, development, and application of validated methodologies for a field study of community response to enable the development of overland sonic boom standards.

Technical Challenge State of the Art: Community response methodology demonstrated using simulated low booms in a controlled community.

Parameter, Value:
Validated criteria established

TRL 2

Technical Challenge Performance Goal: Validate overland sonic boom criteria and test methodology in a field demonstration.

Parameter, Value:
Validated criteria established

TRL 4

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Metrics for sonic boom community response.

Capability Description: Criteria for overland sonic boom levels.

State of the Practice: No community response metric or methodology exists for sonic boom response.

Parameter, Value:
There is no current metric for community response

Technology Outcome: Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise.

Parameter, Value:
Validated criteria established

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Innovation in Commercial Supersonic Aircraft: Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise	Enabling	--	--	2025	4 years

15.2 Innovation in Commercial Supersonic Aircraft
15.2.1 Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise

15.2.1.2 Develop Low Sonic Boom Design Tools

TECHNICAL CHALLENGE

Technical Challenge Description: Develop tools and technologies enabling the design of supersonic aircraft that reduce sonic boom noise to 80 PLdB validated as ready for application in a flight demonstrator.

Research Theme: Integrated Design Solutions for Revolutionary High-Speed Aircraft - Research and development of validated analysis tools and technologies that enable the low sonic boom design of supersonic aircraft.

Technical Challenge State of the Art: Design tools for shaping aircraft to achieve sonic boom level of 80 PLdB, have been demonstrated using subscale models in wind tunnels.

Parameter, Value:
Sonic boom perceived noise level: 80 PLdB.

TRL 2

Technical Challenge Performance Goal: Validated tools and techniques that reduce sonic boom levels to 80 PLdB.

Parameter, Value:
Sonic boom perceived noise level: 80 PLdB.

TRL 4

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Low-boom design tools.

Capability Description: Validated design tools for optimized design of low sonic boom, supersonic aircraft.

State of the Practice: No validated supersonic commercial transport design tools exist for sonic boom reduction.

Parameter, Value:
Sonic boom perceived noise level: 105 PLdB

Technology Outcome: Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise.

Parameter, Value:
Sonic boom perceived noise level: 80 PLdB

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Innovation in Commercial Supersonic Aircraft: Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise	Enabling	--	--	2025	5 years

15.2 Innovation in Commercial Supersonic Aircraft
15.2.2 Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports

15.2.2.1 Design and Develop Low-Noise Propulsion Tools and Concepts for Low-Boom Aircraft

TECHNICAL CHALLENGE

Technical Challenge Description: Develop design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) stage 4 demonstrated in ground test.

Research Theme: Minimize airport community noise impact of high-speed aircraft - Research and development of validated analysis tools and technologies to enable low airport noise propulsion systems design for supersonic aircraft.

Technical Challenge State of the Art: Three stream nozzle concepts moderate bypass ratio propulsion systems demonstrated at laboratory scale with noise levels of 10 dB less than ICAO/FAA stage 4.

Parameter, Value:
dB over ICAO/FAA stage 4: 10 dB

TRL 2

Technical Challenge Performance Goal: Validated, innovative concepts for integrated supersonic propulsion systems.

Parameter, Value:
dB less than ICAO/FAA stage 4: 10 dB

TRL 3

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Low-noise propulsion for supersonic aircraft.

Capability Description: Propulsion systems for low-noise supersonic aircraft.

State of the Practice: The propulsion system used on a retired supersonic transport aircraft is the only 'relevant environment' case and used 1960s technology. Relative to Federal Acquisition Regulations (FAR) Part 36 Stage 3, the aircraft was approximately 65 dB cumulative above stage 3 levels (75 dB cumulative above ICAO/FAA stage 4).

Parameter, Value:
Cumulative above Stage 3 noise levels: 65 dB (75 dB over ICAO/FAA stage 4)

Technology Outcome: Introduction of Affordable, Low-boom, Low-noise, and Low-emission Supersonic Transports.

Parameter, Value:
dB below ICAO/FAA stage 4 noise requirements: 10 dB

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Innovation in Commercial Supersonic Aircraft: Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports	Enabling	--	--	2035	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.1 Demonstrate Innovative Flow Control

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate drag reduction of 8 percent, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, without significant penalties in weight, noise, or operational complexity.

Research Theme: Advanced Ultra-efficient Airframes - Research and development of tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Use of sweeping jet actuators to augment control on the rudder of a vertical tail demonstrated in large-scale testing at relevant speeds. Drag reduction would come through resizing vertical tail.

Parameter, Value:	TRL
Reduce total cruise drag by 1.5% for large twin aisle class aircraft with geared turbo fan engine	5

Technical Challenge Performance Goal: Demonstrate in flight an increase in the control effectiveness of a vertical tail/rudder such that the vertical tail could be resized reducing drag and weight.

Parameter, Value:	TRL
Reduce total cruise drag by 1.5% for large twin aisle class aircraft with geared turbo fan engine	6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Drag reduction techniques for new airframe configurations.

Capability Description: Advanced airframe drag reduction techniques for N+2 levels of performance.

State of the Practice: Currently, there are no innovative flow control concepts in use for transonic transport drag reduction.

Parameter, Value:
Reduce total cruise drag by 1.5% for large twin aisle class aircraft with geared turbo fan engine

Technology Outcome: First Application of N+2 Fixed Wing Performance.

Parameter, Value:
Reduce total cruise drag by 1.5% for large twin aisle class aircraft with geared turbo fan engine

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.2 High-Temperature Turbine Engine Materials

TECHNICAL CHALLENGE

Technical Challenge Description: Develop high-temperature (2,700° F) materials for turbine engines that enable a 6 percent reduction in fuel burn for commercial aircraft, compared to current state of the art materials.

Research Theme: Advanced Ultra-Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan Thrust Specific Fuel Consumption (TSFC), propulsion, noise, and emissions.

Technical Challenge State of the Art: 2,700° F capable engine materials were developed in the laboratory environment.

Parameter, Value:	**TRL**
Temperature capability of engine ceramic matric composite (CMC) material system: 2,700° F	2

Technical Challenge Performance Goal: CMC material systems that can reliably operate at temperatures as high as 2,700° F, reducing or eliminating the requirement for cooling, thereby increasing engine fuel efficiency.

Parameter, Value:	**TRL**
Temperature capability of engine CMC material system: 2,700° F	5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Improved engine fuel efficiency.

Capability Description: High-temperature materials that enable reduction in fuel burn and increased engine efficiency.

State of the Practice: Very limited to no use of CMC materials in current commercial transport engines. Current use of superalloys limited to 2,100° F metal temperature, requiring blade cooling with engine bleed air.

Parameter, Value:
Temperature capability of superalloy engine materials: 2,100° F

Technology Outcome: First Application: N+2 Fixed Wing Performance.

Parameter, Value:
Temperature capability of CMC engine material system: 2,700° F

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.3 Demonstrate Advanced Composites for Weight Reduction

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate weight reduction of 10 percent compared to current state of the art composites, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while enabling lower drag airframes and maintaining safety margins at the aircraft system level.

Research Theme: Advanced Ultra-Efficient Airframes - Research and development of tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Design and manufacture unitized composite stitch construction for a multi-bay box, as well as design manufacturer and test an adaptive compliant flap surface.

Parameter, Value:	TRL
Reduce structural weight by 20% for composites and 5% for adaptive complaint surface for a large twin aisle class aircraft with geared turbo fan engine	4

Technical Challenge Performance Goal: Demonstrate low-weight, damage-tolerant stitch unitized composite structural concept and adaptive compliant surface technology in the flight environment.

Parameter, Value:	TRL
Reduce structural weight by 20% for composites and 5% for adaptive complaint surface for a large twin aisle class aircraft with geared turbo fan engine	5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Lightweight composite technologies that reduce structural weight.
Capability Description: Advanced composite construction techniques which reduce structural weight contributing to airframe efficiency while maintaining margins.

State of the Practice: Current composite construction uses traditional metallic structural design techniques.

Parameter, Value:
Reduce structural weight by 20% for composites and 5% for adaptive complaint surface for a large twin aisle class aircraft with geared turbo fan engine

Technology Outcome: First Application of N+2 Fixed Wing Performance.

Parameter, Value:
Reduce structural weight by 20% for composites and 5% for adaptive complaint surface for a large twin aisle class aircraft with geared turbo fan engine

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.4 Demonstrate Advanced Ultra High Bypass (UHB) Engine Designs for Specific Fuel Consumption and Noise Reduction

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate ultra high bypass (UHB) efficiency improvements to achieve 15 percent thrust specific fuel consumption (TSFC) reduction, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while reducing engine system noise and minimizing weight, drag, nitrogen oxides (NOx), and integration penalties at aircraft system level.

Research Theme: Advanced Ultra-Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan TSFC, propulsion, noise, and emissions.

Technical Challenge State of the Art: Two-stage test of legacy research compressor and second generation geared turbo fan test with low loss fan exit guide vanes and development and test of over-the-rotor and soft vane technologies.

Parameter, Value:	TRL
Reduce TSFC by 2.5% for a lighter than air (LTA) class aircraft with direct drive engine and achieve 9% reduction in propulsor TSFC and 15 EPNdB reduction in propulsor noise on LTA class aircraft with geared engine	4

Technical Challenge Performance Goal: Demonstrate front block compressor technologies to enable high-pressure ratio core compressors and demonstrate and validate the fuel burn and noise performance of an integrated GTF architecture.

Parameter, Value:	TRL
Reduce TSFC by 2.5% for a LTA class aircraft with direct drive engine and achieve 9% reduction in propulsor TSFC and 15 EPNdB reduction in propulsor noise on LTA class aircraft with geared engine	5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: High-efficiency commercial aircraft propulsion.
Capability Description: High-pressure compressor and vane technology for commercial aircraft providing greater fuel efficiency and noise reduction.

State of the Practice: Geared turbofan engine with bypass ratio of 12:1.

Parameter, Value:
Reduce TSFC by 2.5% for a LTA class aircraft with direct drive engine and achieve 9% reduction in propulsor TSFC and 15 EPNdB reduction in propulsor noise on LTA class aircraft with geared engine

Technology Outcome: First Application of N+2 Fixed Wing Performance.

Parameter, Value:
Reduce TSFC by 2.5% for a LTA class aircraft with direct drive engine and achieve 9% reduction in populsor TSFC and 15 EPNdB reduction in propulsor noise on LTA class aircraft with geared engine

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.5 Demonstrate Advanced Combustor Designs for Reduction in Nitrogen Oxides (NOx)

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate reductions of landing and take-off nitrogen oxides (NOx) by 75 percent and cruise NOx by 70 percent from Committee on Aviation Environmental Protection (CAEP6), while minimizing the impact on fuel burn at the aircraft system level, without penalties in stability and durability of the engine.

Research Theme: Advanced Ultra-Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan Thrust Specific Fuel Consumption (TSFC), propulsion, noise, and emissions.

Technical Challenge State of the Art: Technologies for single injector and single nozzles have been demonstrated in test rigs.

Parameter, Value:

Parameter, Value	TRL
75% landing and take-off (LTO) NOx reduction verses CAEP6 for a lighter than air (LTA) class aircraft with geared engine	4

Technical Challenge Performance Goal: Demonstrate emissions goals through sector rig and full annular rig combustor testing.

Parameter, Value:

Parameter, Value	TRL
75% LTO NOx reduction verses CAEP6 for a LTA class aircraft with geared engine	5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Advanced combustor for high-pressure and high bypass ratio engines.

Capability Description: Provide more efficient operations of combustors and engines to reduce emissions.

State of the Practice: Large engines produce landing and take-off NOx that are approximately 50% less than CAEP6 levels, but are still greater than NASA goals.

Parameter, Value:

75% LTO NOx reduction versus CAEP6 for a LTA class aircraft with geared engine

Technology Outcome: First Application of N+2 Fixed Wing Performance.

Parameter, Value:

75% LTO NOx reduction versus CAEP6 for a LTA class aircraft with geared engine

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.6 Demonstrate Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate reduced component noise signatures leading to a 42 EPNdB International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) stage 4 noise margin for the aircraft system while minimizing weight and integration penalties to enable 50 percent fuel burn reduction at the aircraft system level.

Research Theme: Advanced Airframe-Engine Integration - Research and development of innovative approaches and the supporting tools and technologies to reduce perceived noise and aircraft fuel burn through integrated airframe-engine concepts.

Technical Challenge State of the Art: Development of Hybrid Wing Body (HWB) Propulsion Airframe Integration (PAI) concepts and noise reducing landing gear and flap edge components tested in a wind tunnel.

Parameter, Value: Reduce component level landing gear noise by 2.0 EPNdB and flap noise by 4.0 EPNdB for a single aisle class aircraft and reduce mission fuel burn by 50% and community noise by 42 EPNdB on a HWB aircraft with geared engine

TRL: 3

Technical Challenge Performance Goal: Wind tunnel testing of HWB PAI configuration and validation of tools and comparison of full-scale computational fluid dynamics (CFD) analysis with wind tunnel test results.

Parameter, Value: Reduce component level landing gear noise by 2.0 EPNdB and flap noise by 4.0 EPNdB for a single aisle class aircraft and reduce mission fuel burn by 50% and community noise by 42 EPNdB on a HWB aircraft with geared engine

TRL: 5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Reduce airframe noise and fuel burn using advanced aircraft configuration concepts.

Capability Description: HWB PAI concepts and computational analysis for gear and flap noise reduction.

State of the Practice: Current configurations obtain most of their noise and fuel burn benefits through reducing engine source noise by increasing engine bypass ratio, engine acoustic liners, and chevron mixers on fan nozzles. Limited airframe integration approaches are utilized for noise reduction.

Parameter, Value: Reduce component level landing gear noise by 2.0 EPNdB and flap noise by 4.0 EPNdB for a single aisle class aircraft and reduce mission fuel burn by 50% and community noise by 42 EPNdB on a HWB aircraft with geared engine

Technology Outcome: First Application of N+2 Fixed Wing Performance.

Parameter, Value: Reduce component level landing gear noise by 2.0 EPNdB and flap noise by 4.0 EPNdB for a single aisle class aircraft and reduce mission fuel burn by 50% and community noise by 42 EPNdB on a HWB aircraft with geared engine

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.1 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025

15.3.1.7 40% Reduction in Computational Fluid Dynamics (CFD) Error for Aeronautical Flows

TECHNICAL CHALLENGE

Technical Challenge Description: Identify and downselect critical turbulence, transition, and numerical method technologies for 40 percent reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows and shock-boundary layer interactions on state of the art high performance computing hardware.

Research Theme: Advanced Ultra-Efficient Airframes - Research and development of tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Current computational fluid dynamics (CFD) capability is dependably accurate only near the design point of the flight envelope where separation is not a factor. CFD approaches with potential to capture flow separation and transition accurately are computationally unaffordable for real air vehicle configurations with current best algorithms and models.

Parameter, Value:
Percent decrease in CFD error: 0%

TRL
3

Technical Challenge Performance Goal: Demonstrate improved accuracy of CFD predictions across the entire flight envelope, including high lift and operating conditions with flow separation.

Parameter, Value:
Percent decrease in CFD error: 40%

TRL
6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Advances in computer hardware and appropriate algorithms to take advantage of these advances.

TECHNICAL WORK

Needed Capability: Reliable CFD prediction capability across the full flight envelope to enable analysis, design, and optimization of future improved-efficiency air vehicles.

Capability Description: Improved turbulence models, transition models, and numerical algorithms for fast, accurate, and robust computational simulation of novel air vehicle configurations.

State of the Practice: Current CFD capability is dependably accurate only near the design point of the flight envelope where separation is not a factor. Errors are large as the edge of the flight envelope is approached.

Parameter, Value:
Percent decrease in CFD error: 0%

Technology Outcome: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2035.

Parameter, Value:
Percent decrease in CFD error: 40%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2025	Enabling	--	--	2025	6 years

15.Ultra-Efficient Commercial Vehicles
15.3.2 Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035

15.3.2.1 Demonstrate Variable Speed Power Turbine (VSPT) Concept

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate 50 percent improvement in efficient operational capability using a variable speed power turbine concept.

Research Theme: Clean and Efficient Rotorcraft Propulsion - Demonstration and maturation of engine and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalties.

Technical Challenge State of the Art: Rotor speed variation is limited to 10-15 percent for existing rotorcraft through power turbine speed change.

Parameter, Value: Power turbine speed range: 15%

TRL: 2

Technical Challenge Performance Goal: Broaden power turbine speed range to affect larger rotor speed change.

Parameter, Value: Power turbine speed range: 50%

TRL: 4

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Improved simulation capability for multistage turbines with low Reynolds number transitional flow, conceptual design tools at the engine component level, and component testing (e.g., rotordynamics, advanced turbine blade aerodynamic performance) that provides validation data.

TECHNICAL WORK

Needed Capability: Vertical lift engine and drive system technologies that enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalty.

Capability Description: Ability to vary main rotor speed over a wide range using a variable-speed power turbine.

State of the Practice: Current main rotor speed change via power turbine speed change is limited to 10-15 percent – an insufficient amount to achieve operational efficiency and noise-management potential. Turbine efficiency is poor while operating in high aero load/ off-design/ low-Re conditions.

Parameter, Value: Power turbine speed range: 15%

Technology Outcome: First Application of N+3 and N+4 Fixed Wing Performance.

Parameter, Value: Power turbine speed range: 50%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035	Enabling	--	--	2035	6 years

15.Ultra-Efficient Commercial Vehicles
15.3.2 Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035

15.3.2.2 Demonstrate Two-Speed Drive System

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate two-speed drive system with less than 2 percent power loss while maintaining current power-to-weight ratios.

Research Theme: Clean and Efficient Rotorcraft Propulsion - Demonstration and maturation of engine and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalties.

Technical Challenge State of the Art: Currently, single speed transmissions–fixed gear ratio between gas turbine and rotor–are used. Engine speed variation is used to vary rotor speed.

Parameter, Value:
Rotor speed variation: 15%

TRL 2

Technical Challenge Performance Goal: Demonstrate a two-speed drive system to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalty.

Parameter, Value:
Rotor speed variation: 50%

TRL 4

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Conceptual design tools at the component level, variable-speed test rig, test of lightweight composite components, accurate windage simulations and experiments, advanced clutching mechanisms, novel gear designs.

TECHNICAL WORK

Needed Capability: Vertical lift engine and drive system technologies that enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalty.

Capability Description: Main rotor speed change of 50 percent through gearbox speed reduction with NASA-patented transmission designs. Unique experimental variable speed transmission facility. Lightweight dynamic composite components for drive systems.

State of the Practice: Main rotor speed is varied via engine speed (throttle push), which is limited to 10%-15% variation.

Parameter, Value:
Rotor speed variation: 15%

Technology Outcome: First Application of N+3 and N+4 Fixed Wing Performance.

Parameter, Value:
Rotor speed variation: 50%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2035	Enabling	--	--	2035	6 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.1 Enable an Increase in Optimal Aspect Ratio

TECHNICAL CHALLENGE

Technical Challenge Description: Enable a 1.5x to 2x increase in the aspect ratio of a lightweight wing with safe flight control and structures (compared to 2005 best in class).

Research Theme: Advanced Ultra-Efficient Airframes - Research and development of the tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Tailored load path structural design, advanced materials, active structural control, active flow control, and unconventional aero-structural configurations.

Parameter, Value: Percent increase in the aspect ratio of an optimal wing: 50-100%

TRL: 2

Technical Challenge Performance Goal: Demonstrate technologies that enable higher aspect ratio optimal wing designs that are lighter and more efficient.

Parameter, Value: Percent Increase in the aspect ratio of an optimal wing: 50-100%

TRL: 3

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Lightweight, low-drag wings contributing to aircraft fuel burn reduction while maintaining safety.

Capability Description: Integrated aerodynamic, structural, and control technologies for higher aspect ratio, lightweight designs.

State of the Practice: The aspect ratio of an optimal wing is a vehicle-specific balance of many factors, including but not limited to drag, weight, and span. Achieved using traditional structural design and manufacturing with advanced lower density materials (i.e., composite structure is thought of as "black aluminum"), turbulent supercritical airfoils, and wing tip treatments dependent on span constraints.

Parameter, Value: Percent increase in the aspect ratio of an optimal wing: 0%

Technology Outcome: Contribute to Achieving Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value: Percent increase in the aspect ratio of an optimal wing: 50-100%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	5 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.2 Reduce Composites Design and Testing Effort and Cycle Time

TECHNICAL CHALLENGE

Technical Challenge Description: Develop analytical methods and rapid-design tools to reduce structural design cycle time and testing effort by 30 percent during development and certification.

Research Theme: Advanced Ultra-Efficient Airframes - Research and development of the tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Development of high-fidelity predictive tools for predicting the failure initiation load, failure progression, and final failure load has been validated at the sub-Element level within the building block approach for a composite airframe structure.

Parameter, Value:
Percent failure load prediction error: 15%

TRL
3

Technical Challenge Performance Goal: Develop high-fidelity predictive tools for progressive damage analysis and transient dynamic analysis sufficient to replace physical tests applicable to the certification process.

Parameter, Value:
Percent failure load prediction error: 5%

TRL
5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Aircraft original equipment manufacturer (OEM) participation and incorporation of the newly developed methods.

TECHNICAL WORK

Needed Capability: Reliable, validated composite design and analysis tools for better preliminary designs, fewer redesigns, and less development and certification testing.

Capability Description: More accurate failure predictions for advanced composite airframe and engine casing architectures.

State of the Practice: Analysis calibrated to test results for sub-elements of final structure, not truly predictive with low confidence for certification. Requires significant validation testing.

Parameter, Value:
Percent failure load prediction error: 15%

Technology Outcome: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:
Percent failure load prediction error: 5%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	5 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.3 Enable Rapid Inspection of Composites

TECHNICAL CHALLENGE

Technical Challenge Description: Increase inspection throughput phases by 30 percent through development of quantitative and practical inspection methods, data management methods, models, and tools.

Research Theme: Advanced Ultra-Efficient Airframes - Research and development of the tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Development of automated systems coupled with data analysis, resulting in reduction of inspection and analysis time.

Parameter, Value:

Reduced inspection time for flat laminates with known damage/ defects: 30%

TRL 2

Technical Challenge Performance Goal: Improved inspection throughput through the development of quantitative and practical inspection methods, and data management methods and tools.

Parameter, Value:

A fully-integrated, non-desctructive inspection methodology over current manual operating procedures: 30%

TRL 6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Aircraft original equipment manufacturer (OEM) participation and incorporation of the newly developed methods.

TECHNICAL WORK

Needed Capability: Reduction of the total inspection throughput and analysis capabiltity for composite structures to reduce total development and certification cost.

Capability Description: Increase inspection throughput by combining advanced quantitative and practical inspection methods with data management.

State of the Practice: Non-destructive inspection (NDI) techniques, skilled or subjective interpretation of data, and manual disposition.

Parameter, Value:

Inspection time reduction over standard operating procedures: 0%

Technology Outcome: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:

Inspection time reduction over standard operating procedures: 30%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	5 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.4 Streamline Composites Manufacturing

TECHNICAL CHALLENGE

Technical Challenge Description: Streamline automated manufacturing technologies for better quality control, reduced defects, and fewer iterations to reach manufacturing certification.

Research Theme: Advanced Ultra-Efficient Airframes - Research and development of the tools and technologies to enable new airframe configurations with high levels of aerodynamic performance, lower structural weight, and innovative approaches to noise reduction.

Technical Challenge State of the Art: Developing Automated Fiber Placement (AFP) and Design for Manufacturability software to combine with improved co-cure/co-bond, and cure process modeling tools.

Parameter, Value:	TRL
As-built part contains acceptable level of defects: 75% of the time	3

Technical Challenge Performance Goal: Demonstrate increased composite quality and defect prediction accuracy using advanced automated technology and computational simulation tools.

Parameter, Value:	TRL
As-built part contains acceptable level of defects: 95% of the time	6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Aircraft original equipment manufacturer (OEM) participation and incorporation of the newly developed methods..

TECHNICAL WORK

Needed Capability: Enhanced manufacturing processes and tools that eliminate random defects and provide parts that can be manufactured as designed.

Capability Description: Develop predictive tools for AFP, co-cure/co-bond defects, and cure process models.

State of the Practice: Unable to predict fiber placement and cure-induced defects, trial-and-error iterations lead to part variability and rework/redesign.

Parameter, Value:
As-built part contains acceptable level of defects: 75% of the time

Technology Outcome: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:
As-built part contains acceptable level of defects: 95% of the time

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	5 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.5 Reduce Fan and High-Lift Noise

TECHNICAL CHALLENGE

Technical Challenge Description: Reduce fan (lateral and flyover) and high-lift system (approach) noise on a component basis by 4 dB with minimal impact on weight and performance.

Research Theme: Advanced Component Noise Reduction - Improvements in propulsion, airframe, and other subsystem components to achieve noise reduction.

Technical Challenge State of the Art: Multiple degree of freedom liners, and concepts for slat/flap edge, gap, and cove noise reduction using advanced material/structural concepts.

Parameter, Value: | **TRL**
Reduction in component noise: 4 dB | 3

Technical Challenge Performance Goal: Demonstrate technologies that reduce fan and high-lift system component noise with minimal impact on weight and performance.

Parameter, Value: | **TRL**
Reduction in component noise: 4 dB | 5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Reduced perceived community noise approaching noise contained within airport boundaries, with minimal impact on weight and performance.

Capability Description: Integrated aero-acoustic-structural component-level technologies that reduce noise during take-off and landing.

State of the Practice: Propulsion system noise reduction via increasing bypass ratio systems and concepts, such as chevrons. Single degree of freedom liner technology. Turbulence generating bluff bodies (e.g., landing gear) and vortex generating edges (e.g., flaps) have been altered through mainly expert cut and try tactics using local shape changes to modify noise characteristics.

Parameter, Value:
Reduction in component noise: 0 dB

Technology Outcome: Contribute to Achieving Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:
Reduction in component noise: 4 dB

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	4 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.6 Enable Low Nitrogen Oxides (NOx) Fuel Flex Combustor – Propulsion

TECHNICAL CHALLENGE

Technical Challenge Description: Reduce nitrogen oxides (NOx) emissions from fuel-flexible combustors to 80 percent below the Committee on Aviation Environmental Protection (CAEP6) standard with minimal impacts on weight, noise, or component life.

Research Theme: Advanced Ultra-Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan thrust specific fuel consumption, propulsion noise, and emissions.

Technical Challenge State of the Art: Ceramic matrix composite (CMC) development for high-temperature combustor liner, high-pressure spray, lean direct injection, and active combustor control. “ERA” designs for physically larger combustors show promise at TRL 3/4 for CAEP6: 75 to 80%.

Parameter, Value:	TRL
Percent NOx emissions reduction relative to CAEP6 standard, landing and take-off (LTO): 80% for Operating Pressure Ratio (OPR)50+	2

Technical Challenge Performance Goal: Demonstrate technologies that enable reduction of LTO NOx for high OPR compact gas generators.

Parameter, Value:	TRL
Percent NOx emissions reduction relative to CAEP6 standard, LTO: 80% for OPR50+	3

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Fuel-flexible combustor compatible with high-OPR (50+) compact gas generators with minimal impacts on weight, noise, or component life.

Capability Description: Cleaner combustion (NOx, particulates, etc.) with minimal impact on weight and performance using advanced hot section materials, lean injection, and active combustion control; applicable to a range of alternative fuels.

State of the Practice: NOx emissions and thrust specific fuel consumption (TSFC) are traded for a balanced system solution. High temperatures used to increase thermal efficiency (reduce TSFC) also increase NOx emissions. State of the art combustion injection, mixing, and stability technology cause local hot spots that further increase the harmful emissions. Current aircraft have been designed to use conventional jet fuel from petroleum resources and are now used with a variety of new drop-in, alternative fuels.

Parameter, Value:
Percent NOx emissions reduction relative to CAEP6 standard, LTO: 60% for OPR30

Technology Outcome: Contribute to Achieving Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:
Percent NOx emissions reduction relative to CAEP6 standard, LTO: 80% for OPR50+

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	5 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.7 Enable Compact High Operating Pressure Ratio (OPR) Gas Generator

TECHNICAL CHALLENGE

Technical Challenge Description: Enable reduced size/flow gas generators with 50+ Operating Pressure Ratio (OPR) and disk/seal temperatures of 1,500° F with minimal impact on noise and component life.

Research Theme: Advanced Ultra-Efficient Propulsion - Research and development of the tools and technologies to reduce turbofan thrust specific fuel consumption, propulsion noise, and emissions.

Technical Challenge State of the Art: Advanced disk alloys and coatings with higher temperature capability. Ceramic matrix composite (CMC) with higher temperature capability. Active/ passive aerodynamics and control concepts to minimize aerodynamic losses due to short blades/relatively large gaps.

Parameter, Value:	TRL
Unknown (need integrating parameter that captures 1,500° F OPR50+ system)	2

Technical Challenge Performance Goal: Increased temperature capability of hot section materials and reduced aerodynamic tip/endwall losses for small blades to enable high OPR.

Parameter, Value:	TRL
Unknown (need integrating parameter that captures 1,500° F OPR50+ system)	4

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Efficient, compact gas generators to allow BPR to grow without growing OML size to facilitate airframe integration.
Capability Description: High-temperature, high-OPR engine performance using high-temperature components and low-loss tip/endwall aerodynamics; compatible with/incorporates the low NOx fuel-flexible combustor technology.

State of the Practice: Current practical systems are limited to OPRs of approximately 40 with bypass ratios of approximately 12. Today's seals are limited to 1,100° F. Current powder metallurgy disk alloys in commercial engines are capable of 1,300° F.

Parameter, Value:
Unknown (need integrating parameter that captures 1,100-1,300° F, OPR30-40 system)

Technology Outcome: Contribute to Achieving Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:
Unknown (need integrating parameter that captures 1,500° F OPR50+ system)

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	5 years

15.3 Ultra-Efficient Commercial Vehicles
15.3.3 Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035

15.3.3.8 Demonstrate Integrated Boundary Layer Ingestion (BLI) System

TECHNICAL CHALLENGE

Technical Challenge Description: Achieve a vehicle-level net system benefit with a distortion-tolerant inlet/fan, boundary-layer ingesting propulsion system on a representative vehicle.

Research Theme: Advanced Airframe-Engine Integration - Research and development of innovative approaches and the supporting tools and technologies to reduce perceived noise and aircraft fuel burn through integrated airframe-engine concepts.

Technical Challenge State of the Art: Multidisciplinary design of a integrated inlet/fan system with a distortion-tolerant fan; novel airframe/boundary layer ingestion (BLI) propulsion system integration.

Parameter, Value:	TRL
Percent reduction in energy usage due to BLI during cruise: 5%	2

Technical Challenge Performance Goal: Demonstrate a BLI distortion-tolerant inlet/fan system with minimal loss of efficiency for fan stage with distorted inflow; demonstrate aero-propulsive benefit of installed BLI system.

Parameter, Value:	TRL
Percent reduction in energy usage due to BLI during cruise: 5%	3

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Propulsion/airframe integration contribution to aircraft fuel burn reduction.
Capability Description: Provides a propulsion/airframe integration with a net system fuel burn benefit through drag reduction and increased propulsive efficiency.

State of the Practice: BLI is not used in current transport aircraft designs.

Parameter, Value:
Percent reduction in energy usage due to BLI during cruise: 0%

Technology Outcome: Contribute to Achieving Community Goals for Improved Vehicle Efficiency and Environmental Performance beyond 2035.

Parameter, Value:
Percent reduction in energy usage due to BLI during cruise: 5%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Ultra-Efficient Commercial Vehicles: Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035	Enabling	--	--	2035	3 years

15.4 Transition to Low-Carbon Propulsion
15.4.1 Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems

15.4.1.1 Characterize Alternative Fuel Emissions at Cruise

TECHNICAL CHALLENGE

Technical Challenge Description: Conduct fundamental characterization of a representative range of alternative fuel emissions at cruise altitude.

Research Theme: Characterization and Integration of Alternative Fuels. Characterization of alternative fuels, combustor concepts, and their integration requirements.

Technical Challenge State of the Art: Limited property data for many alternate fuels, except for 50/50 blends of petroleum and Fischer-Tropsch; emissions characteristics measured on the ground in facilities for behind engines.

Parameter, Value:
Gaseous (e.g., nitrogen oxides (NOx), carbon monoxide (CO)) and particulate emissions (e.g., soot) at cruise altitude/operation conditions: Emission Index (EI) or particulate count

TRL 3

Technical Challenge Performance Goal: Characterize alternative fuel emissions at cruise altitude and operating conditions in flight.

Parameter, Value:
Gaseous (e.g., NOx, CO) and particulate emissions (e.g., soot) at cruise altitude/operation conditions: EI or particulate count

TRL 5

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Characteristics of alternative fuel emissions at cruise altitudes.

Capability Description: Characterize alternative fuel emissions in-flight at cruise conditions altitudes.

State of the Practice: Current fuels are made from petroleum, but 50/50 blends Fischer-Tropsch and HEFA (organic) fuels with standard jet fuel are now certified for flight. Very limited emissions data exist on newly-certified fuels, and potential new fuels. No emissions data at cruise altitude conditions, and fuel effects on plume chemistry and contrails are not known.

Parameter, Value:
Gaseous (e.g., NOx, CO) and particulate emissions (e.g., soot) at cruise altitude/operation conditions: not available for certified alternative fuels

Technology Outcome: Contribute to the Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems.

Parameter, Value:
Gaseous (e.g., NOx, CO) and particulate emissions (e.g., soot) at cruise altitude/operation conditions: EI or particulate count

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Transition to Low-Carbon Propulsion: Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Enabling	--	--	2025	1 year

15.4 Transition to Low-Carbon Propulsion
15.4.1 Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems

15.4.1.2 Demonstrate Advanced Combustor Design for Nitrogen Oxides Reduction

TECHNICAL CHALLENGE

Technical Challenge Description: Demonstrate reductions of landing and take-off (LTO) nitrogen oxides (NOx) by 75 percent from Committee on Aviation Environmental Protection (CAEP6) and cruise NOx by 70 percent, while minimizing the impact on fuel burn at the aircraft system level, without penalties in stability and durability of the engine system.

Research Theme: Characterization and Integration of Alternative Fuels. Characterization of alternative fuels, combustor concepts, and their integration requirements.

Technical Challenge State of the Art: Technologies for single injector and single nozzles have been demonstrated in test rigs.

Parameter, Value:	TRL
75% LTO NOx reduction versus CAEP6 for a lighter than air (LTA) class aircraft with geared engine	4

Technical Challenge Performance Goal: Demonstrate emissions goals through sector rig and full annular rig combustor testing.

Parameter, Value:	TRL
75% LTO NOx reduction versus CAEP6 for a LTA class aircraft with geared engine	7

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Fuel-flexible combustor compatible with high-Operating Pressure Ratio (OPR) gas generators.

Capability Description: Demonstrate low-emission combustion using alternative fuels.

State of the Practice: NOx emissions and thrust specific fuel consumption (TSFC) are traded for a balanced system solution. High temperatures used to increase thermal efficiency and reduce TSFC also increase NOx emissions. State of the art combustion injection, mixing, and stability technology allow for local hot spots that further increase the harmful emissions. Current aircraft have been designed to use conventional jet fuel from petroleum resources and are now used with a variety of new drop-in, alternative fuels.

Parameter, Value:

75% LTO NOx reduction versus CAEP6 for a LTA class aircraft with geared engine

Technology Outcome: Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems.

Parameter, Value:

75% LTO NOx reduction versus CAEP6 for a LTA class aircraft with geared engine

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Transition to Low-Carbon Propulsion: Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Enabling	--	--	2025	4 years

15.4 Transition to Low-Carbon Propulsion
15.4.1 Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems

15.4.1.3 Enable Low-Nitrogen Oxides (NOx) Fuel Flexible Combustor – Alternative Fuels

TECHNICAL CHALLENGE

Technical Challenge Description: Reduce nitrogen oxides (NOx) emissions from fuel-flexible combustors to 80 percent below the Committee on Aviation Environmental Protection (CAEP6) standard with minimal impacts on weight, noise, or component life.

Research Theme: Characterization and Integration of Alternative Fuels. Characterization of alternative fuels, combustor concepts, and their integration requirements.

Technical Challenge State of the Art: High-Operating Pressure Ratio (OPR) combustor tests are being designed to demonstrate reduction of alternative fuel landing, take-off, and cruise NOx.

Parameter, Value:	TRL
Reduction of landing and take-off (LTO) NOx: not available; Reduction of cruise NOx: not available	4

Technical Challenge Performance Goal: Demonstrate reduction of alternative fuel landing, take-off, and cruise NOx from CAEP6 in a test environment.

Parameter, Value:	TRL
Reduction of LTO and cruise NOx: 80%	7

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: None

TECHNICAL WORK

Needed Capability: Fuel-flexible combustor compatible with high-OPR gas generators.

Capability Description: Demonstrate a low-emission combustor using alternative fuels, compatible with high-OPR gas generators.

State of the Practice: NOx emissions and thrust specific fuel consumption (TSFC) are traded for a balanced system solution. High temperatures used to increase thermal efficiency and reduce TSFC also increase NOx emissions. State of the art combustion injection, mixing, and stability technology allow for local hot spots that further increase the harmful emissions. Current aircraft have been designed to use conventional jet fuel from petroleum resources and are now used with a variety of new drop-in, alternative fuels.

Parameter, Value:
Reduction of LTO and cruise NOx from CAEP6: 0%

Technology Outcome: Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems.

Parameter, Value:
Reduction of LTO and cruise NOx: 80%

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Transition to Low-Carbon Propulsion: Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Enabling	--	--	2025	4 years

15.4 Transition to Low-Carbon Propulsion
15.4.2 Initial Introduction of Alternative Propulsion Systems

15.4.2.1 Establish One or More Gas-Electric Propulsion Concepts

TECHNICAL CHALLENGE

Technical Challenge Description: Establish one or more viable concepts for a 5-10 MW hybrid gas-electric propulsion system for a commercial transport aircraft.

Research Theme: Scalable Alternative Propulsion Systems. Research and development to enable hybrid propulsion concepts.

Technical Challenge State of the Art: Initial conceptual designs under development for both superconduction/cryogenic and non-cryo systems. Developmental motors in 100 kW size for hybrid automobiles are exploring combination of technologies to increase power density. Research into high efficiency/power density electric machines, and integrated power management and distribution.

Parameter, Value:	TRL
Power density: 4 hp/lb	1

Technical Challenge Performance Goal: Establish on paper a viable, flightweight hybrid gas-electric propulsion system design/architecture in the 5-10 MW class for a commercial transport aircraft; identify component technology challenges.

Parameter, Value:	TRL
Aircraft hybrid gas-electric propulsion power: 5-10 MW	2

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Conceptual studies at this point but beyond the studies there is a dependency on energy storage (e.g., batteries) development from outside NASA.

TECHNICAL WORK

Needed Capability: Efficient, flightweight hybrid gas-electric aircraft propulsion with volume compatible with aircraft integration. **Capability Description:** Efficient, high power density electric machines, gas generators, and integrated power management and distribution systems compatible with efficient airframe integration.

State of the Practice: There are no hybrid gas-electric propulsion systems in use today for commerical transport aircraft, though there are other vehicles, such as cars and ships. Power density of motors are in the 3-6 hp/lb range for non-cryo and cryo systems, respectively.

Parameter, Value:
Aircraft hybrid gas-electric propulsion power: 0 MW

Technology Outcome: Contribute to the Initial Introduction of Alternative Propulsion Systems.

Parameter, Value:
Aircraft hybrid gas-electric propulsion power: 5-10 MW

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Transition to Low-Carbon Propulsion: Initial Introduction of Alternative Propulsion Systems	Enabling	--	--	2035	4 years

15.5 Real-Time System-Wide Safety Assurance 15.5.1 Introduction of Advanced Safety Assurance Tools 15.5.2 An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring 15.5.3 Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System	**15.5.1-3.1 Automate Discovery of Precursors**

TECHNICAL CHALLENGE

Technical Challenge Description: Enable automated discovery of precursors to safety incidents.

Research Theme: System-wide Data Analysis for Understanding Safety Events - Technical approaches for integrating sensitive data from heterogeneous sources to build base models of nominal and off-nominal system performance and improve accuracy of detection and prediction tools.

Technical Challenge State of the Art: Developing advanced technologies and tools to analyze hetrogeneous data sets to enable discovery of the unknown rather than searching for the occurance of known issues. These new techniques will be able to study massive data sets including flight, radar track, textual, voice-recorded, and weather data.

Parameter, Value:	TRL
Automated discovery of anomalies and automated discovery of precursors	4

Technical Challenge Performance Goal: Demonstrate the ability to identify fleet-wide anomalies, and their precursors, that can impact safety, maintenance schedules, and operating cost.

Parameter, Value:	TRL
Integrated detection of anomalies and identification of precursors in a tool for use by safety analysts	6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Availability of massive operational data sets to refine and develop tools.

TECHNICAL WORK

Needed Capability: Tools for multidimensional analysis to provide discovery and prediction of anomalous events.

Capability Description: Demonstrate automated discovery of anamolous events and automated discovery of precursors to those events, as well as other known safety incidents.

State of the Practice: Currently, discovery of system-wide precursors to safety incidents is performed manually by safety analysts. Safety threats are discovered through near-misses, incidents or accidents. NASA tools are allowing discovery of unknown anomalies and safety threats.

Parameter, Value:

Detection of anomalies within data from a single airline or a single airport

Technology Outcome: Introduction of Advanced Safety Assurance Tools, An Automated Safety Assurance System Enabling Continuous System-wide Safety Monitoring, Automated Safety Assurance Integrated with Real-time Operations Enabling a Self-protecting Aviation System.

Parameter, Value:

System-wide, real-time detection of anomalies and precursors

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Real-Time System-Wide Safety Assurance: Introduction of Advanced Safety Assurance Tools	Enabling	--	--	2025	6 years
Real-Time System-Wide Safety Assurance: An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring	Enabling	--	--	2035	6 years
Real-Time System-Wide Safety Assurance: Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System	Enabling	--	--	2035	6 years

15.5 Real-Time System-Wide Safety Assurance
15.5.1 Introduction of Advanced Safety Assurance Tools
15.5.2 An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring
15.5.3 Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System

15.5.1-3.2 Prognostic Algorithm Design for Safety

TECHNICAL CHALLENGE

Technical Challenge Description: Develop prognostic algorithms to improve identification and mitigation of safety threats.

Research Theme: Improved Performance of Detection, Analysis, and Prognostic Tools – Increased speed and scaling of tools to enable rapid detection safety threats in large, heterogeneous data sets as they arise.

Technical Challenge State of the Art: Non-deterministic, unverified prognostic algorithms that predict degradation and remaining useful life of flight critcical components.

Parameter, Value:

Prognostic algorithms tested onboard flight vehicle

TRL: 3

Technical Challenge Performance Goal: Verified, on-board prognostic capability.

Parameter, Value:

Demonstrated verifiable, integrated prognostic and decision-making algorithms to support contingency management

TRL: 6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Development of suitable verification techniques for non-deterministic algorithms.

TECHNICAL WORK

Needed Capability: Demonstrate prognostic capabilities to asess and mitigate emerging safety issues.
Capability Description: Demonstrate increased ability to predict and assesses aviation safety issues using verifiable, prognostic algorithms that identify threats, alert pilots, and guide threat mitigation actions.

State of the Practice: Prognostic algorithms have been tested on ground-based and flight vehicles, but techniques to enable verification are not available.

Parameter, Value:

No techniques available for verifying non-deterministic prognostic algorithms that are acceptable for certification

Technology Outcome: Introduction of Advanced Safety Assurance Tools, An Automated Safety Assurance System Enabling Continuous System-wide Safety Monitoring, Automated Safety Assurance Integrated with Real-time Operations Enabling a Self-protecting Aviation System.

Parameter, Value:

At least one method for verifying non-deterministic algorithms accepted

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Real-Time System-Wide Safety Assurance: Introduction of Advanced Safety Assurance Tools	Enabling	--	--	2025	6 years
Real-Time System-Wide Safety Assurance: An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring	Enabling	--	--	2035	6 years
Real-Time System-Wide Safety Assurance: Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System	Enabling	--	--	2035	6 years

15.6 Enable Assured Machine Autonomy for Aviation
15.6.2 Ability to Fully Certify and Trust Autonomous Systems for NAS Operations

15.6.2.1 Assurance of Flight Critical Systems

TECHNICAL CHALLENGE

Technical Challenge Description: Develop verification and validation techniques to instill confidence that new technologies are as safe as (or safer than) the current system and provide a cost-effective basis for assurance and certification of complex civil aviation systems.

Research Theme: Validation, Verification, Testing, and Evaluation: Application of assurance technologies to validate performance of autonomous systems in a variety of known (i.e. conceivable) operational scenarios; extension of traditional verification and validation techniques to ensure trust and confidence in the performance of machine learning, and sense-making autonomy functions capable of adapting to conditions of the unknown unknown type.

Technical Challenge State of the Art: Developing formal methods for assuring flight-critical systems, researching and promoting use off formal methods to develop safety cases acceptable for certification.

Parameter, Value:	TRL
Research into validated tools for assurance of flight-critical systems.	2

Technical Challenge Performance Goal: Demonstrate expedited deployment of flight-critical systems within NextGen simulated environment.

Parameter, Value:	TRL
Existence of validated tools for assurance of flight-critical systems.	6

Technical Challenge Development Dependent Upon Basic Research or Other Technology Candidate: Advancement in research on scalable formal methods.

TECHNICAL WORK

Needed Capability: Cost-effective certified flight critical systems.

Capability Description: Enable earlier life-cycle verification and validation (V&V) of compositional reasoning tools for assessing interactions in large complex systems and operations using scalable software assurance tools to accomodate the complexity of NextGen and autonomous systems.

State of the Practice: Certification of flight-critical aviation systems entails careful, time-consuming capture of requirements, consideration of aircraft-level hazards, and assuring the safety of systems through reviews, analysis, and testing at each level of development.

Parameter, Value:

Costly and less thorough traditional testing and certification of flight-critical systems

Technology Outcome: Ability to Fully Certify and Trust Autonomous Systems for NAS Operations.

Parameter, Value:

Tools for assurance of flight-critical systems that enable NextGen implementation and autonomous opertations through efficient and cost effective assurance of complex systems

Technical Challenge Needed for the Following NASA Strategic Thrust and Roadmap Outcome	Enabling or Enhancing	Strategic Thrust Date	Launch Date	Technical Challenge Need Date	Minimum Time to Mature Technical Challenge
Enable Assured Machine Autonomy for Aviation: Ability to Fully Certify and Trust Autonomous Systems for NAS Operations	Enabling	--	--	2035	8 years